

This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

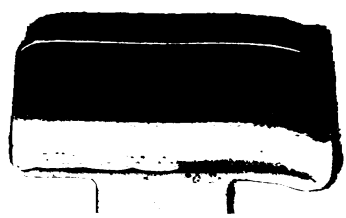
A TEXT-BOOK OF MARINE ENGINEERING

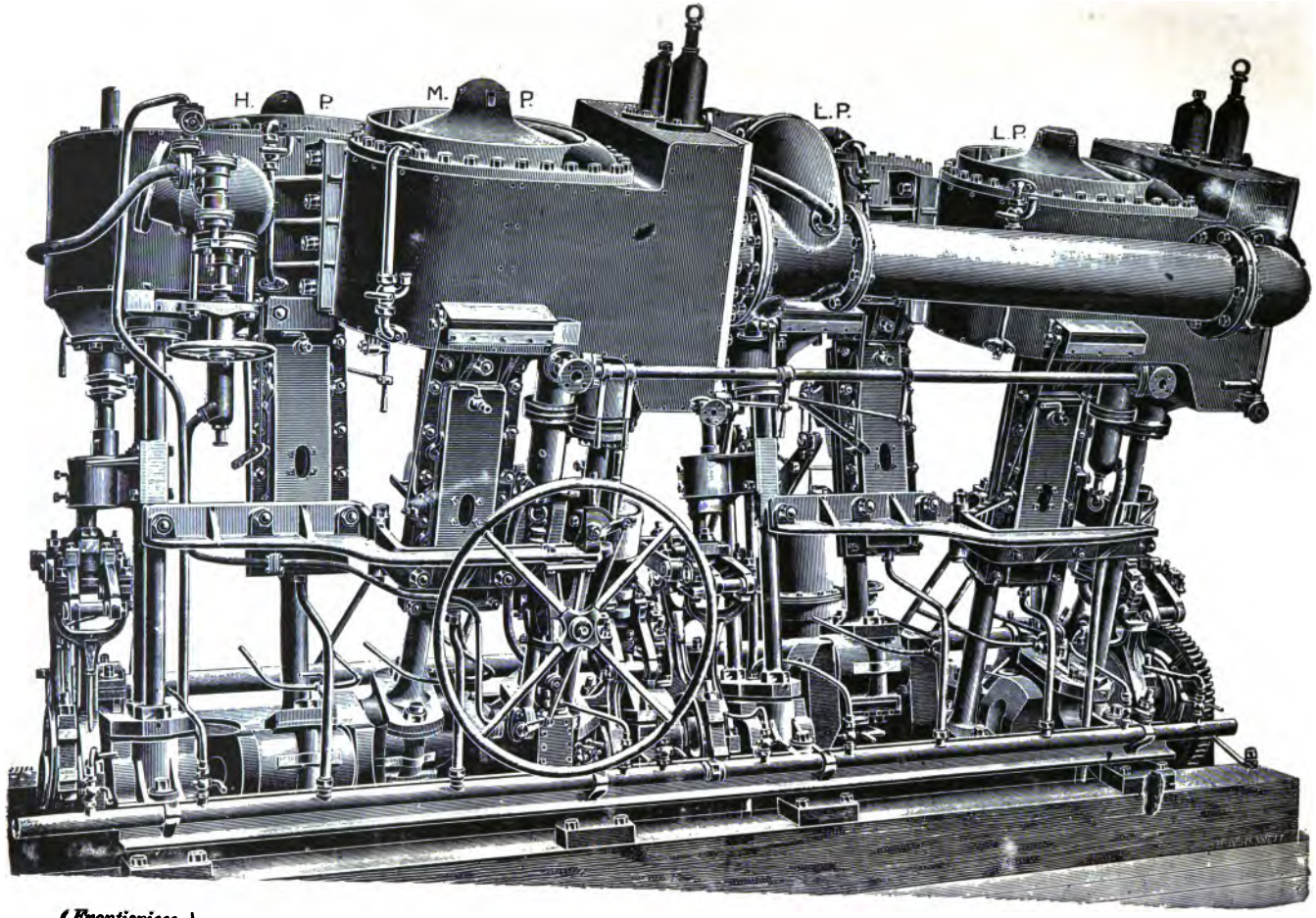
A. E. TOMPKINS, R.N.



GRIFFIN & Co., PORTSMOUTH

Library
of the
University of Wisconsin





(Frontispiece.)

Fig. 43.

(See page 921

A TRE[illegible]

[illegible]NE ENG[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

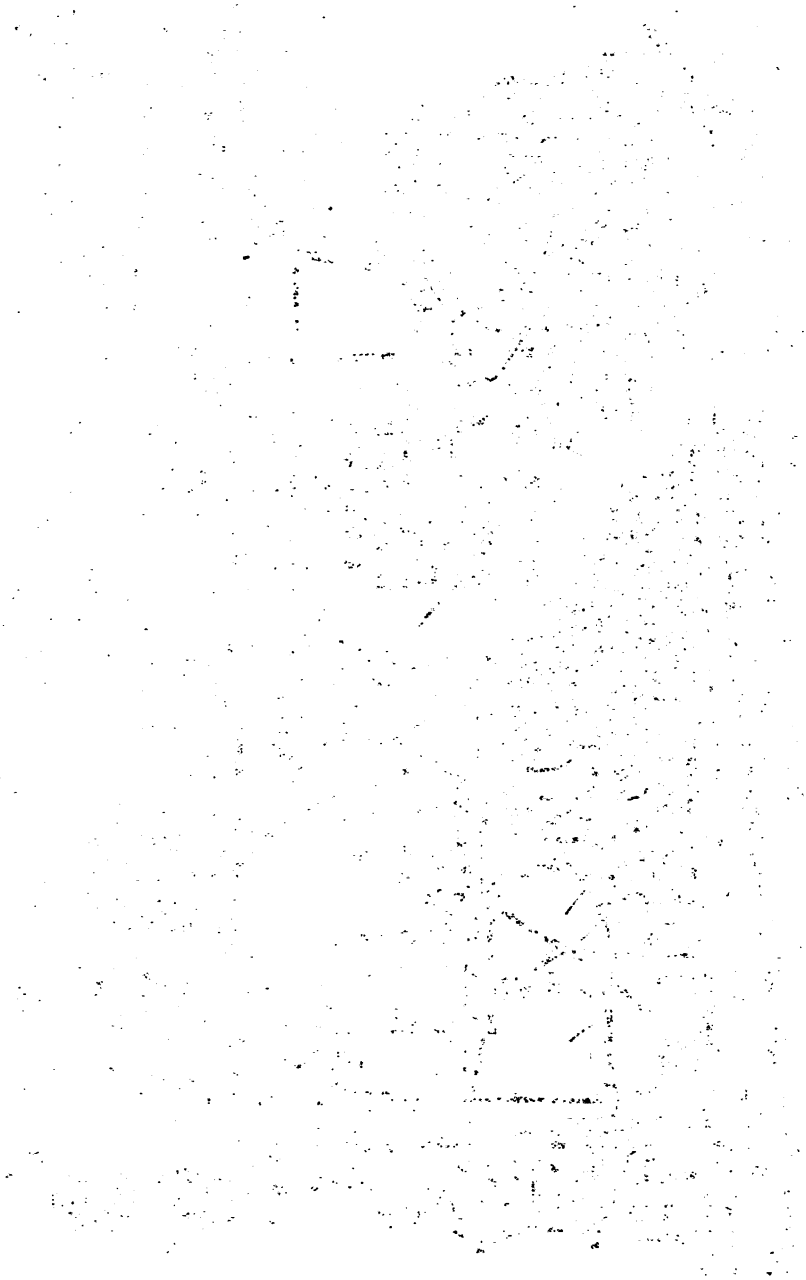
[illegible]

[illegible] H. [illegible]

[illegible] Potter, St[illegible]

[illegible]

[illegible]



A TEXT BOOK

OF

MARINE ENGINEERING

WITH SUPPLEMENT, BELLEVILLE BOILER, &c., &c.

FOR THE USE OF NAVAL OFFICERS, MARINE ENGINEERS, AND STUDENTS OF MARINE AND MECHANICAL ENGINEERING.

BY

A. E. TOMPKINS, CHIEF ENGINEER, ROYAL NAVY.

WITH 142 ILLUSTRATIONS.

1898.

PORTSMOUTH:

J. GRIFFIN & CO., 2, THE HARD.

AGENTS:

LONDON:—Simpkin, Marshall & Co.; and sold by Imray & Son, 89 & 102 Minories; Norie & Wilson, 156, Minories; H. Hughes & Son, 52, Fenchurch Street; J. D. Potter, 31, Poultry.

LIVERPOOL—Philip, Son & Nephew.
GLASGOW—Brown & Son, 35, Mitchel Street; McGregor & Co., Clyde Place.
BERLIN—W. H. Kühl.
SHANGHAI, HONG KONG, YOKOHAMA—Kelly & Walsh.
ST. PETERSBURG—C. Ricker.
TOKIO—Maruya & Co.

All rights of translation reserved.]



64465
AUG 12 1902
TJF
.T59

6966183

PREFACE.

THIS Book is intended principally for the use of sea going engineers, and students of marine and mechanical engineering. The Author hopes that it will also be of use to many naval officers and others who take an interest in the progress and working of marine machinery. Although theoretical considerations have not been, and cannot be, disregarded, they have been explained as briefly as possible in popular language, in conjunction with various recent developments of engineering practice and economy.

Little space has heen devoted to types of machinery which may be of historical interest only, whilst present practice is considered as fully as possible. The general principles dominating the important subject of coal consumption and economy have been brought prominently forward wherever they may have any bearing on the subject treated of.

The design and general engineering practice of the Mercantile Marine has run concurrently with that of the Admiralty especially in fuel and weight saving appliances. The Admiralty have however taken a distinct lead in adopting water tube boilers with largely increased pressures, a lead which after sufficient experience has been gained will no doubt be followed.

Water tube boilers have therefore received a large amount of attention and nearly all the types adopted in the Navy, are illustrated and described with their principal points of difference.

Artificially induced draught is now taking a place among later developments and although no very great economy may be gained by its adoption, it will probably supersede the closed stokehold system, and both boilers and personnel will gain considerably by the change.

It is possible that higher pressures, and the utilization of the heat wasted up the funnel in combination with induced draught may, before the close of the century, permit a production of one horse power for one pound of coal.

A chapter has been devoted to evaporators, feed heaters and filters with their practical working efficiency and theoretical economy. In this direction also we may look for many further developments in the reduction of coal consumption, and increased life of the boilers.

The illustrations and diagrams are not drawn to any particular scale as they are simply intended to assist the letter-press in the explanation of the forms and general principles of the construction of the various parts described.

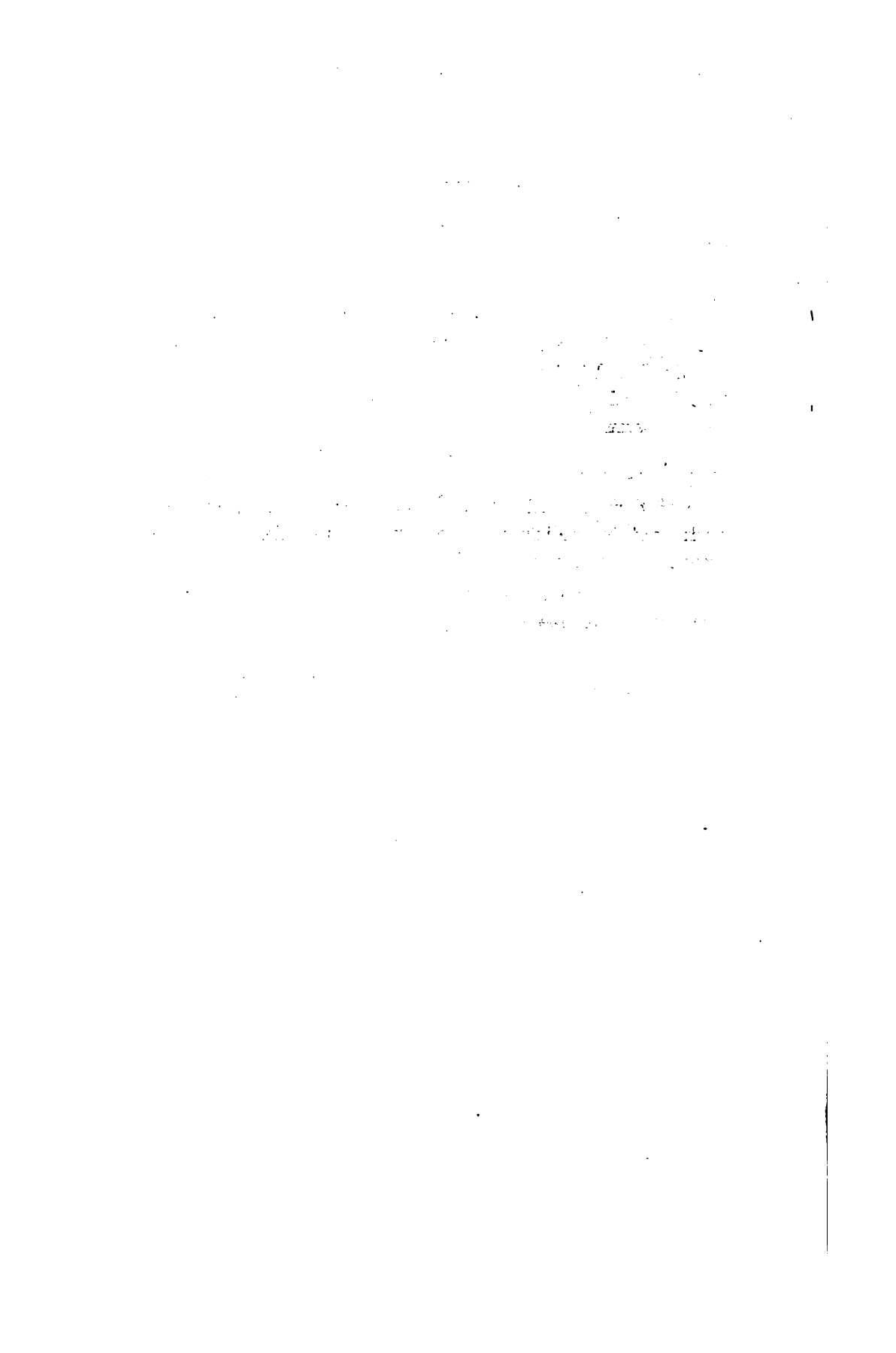
The Author does not lay claim to any great originality for his book, the principles and practice governing engine design have already been very thoroughly discussed in previous works; but it is offered as a summary of the practice of marine engineering of the present day, a subject which from time to time must call for new books as progress advances and that which is in an experimental stage becomes developed and finally adopted.

My best thanks are given to Messrs. Blechynden, Caird and Rayner, Davis and Co., Dewrance and Co., The Glasgow Patents Co., T. S. Mc Innes and Co., D. B. Morison (of Messrs. Thos. Richardson and Son,) J. I. Thornycroft and Co., G. and J. Weir, J. Samuel White, The Worthington Pumping Engine Co., Yarrow and Co., and other gentlemen and firms for their kindness in giving me details and materials for illustrations of some of their specialities, and I regret that in keeping the work within ordinary dimensions, many details have necessarily been omitted.

My best thanks are also due to some of my brother officers who have assisted me in revising the proofs for the press.

A. E. TOMPKINS.

Portsmouth, 1896.



CONTENTS.

Chap.		Page.
I.	The motive power of the Engine	1
II.	Definitions and Units	5
III.	The Boiler	11
IV.	Combustion	41
V.	Fittings and Mountings of Boilers	51
VI.	Care and Maintenance of Boilers	74
VII.	The Engine	83
VIII.	Cylinders and their Fittings	108
IX.	The Shafting and Connecting Rods	118
X.	The slide valve and its motion	130
XI.	Expansion of Steam	147
	Indicator and Indicator Diagrams	
XII.	Auxiliary Machinery	166
XIII.	Evaporators, Feed heaters and Filters ...	179
XIV.	Care and Management of Machinery	204
XV.	Propulsion	210
XVI.	Ventilation, Watertight Doors and Pumping Arrangements	224

ADDITIONAL SUPPLEMENT.

The Water-tube boilers of the Interim Report ...	283
Instructions for working Belleville boilers	290
Niclausse boiler, construction and working	294
Dürr boiler, construction and working	302
Thornycroft-Marshall boiler	307
Babcock and Willcox boiler	311
Performances of water-tube boilers	318

ILLUSTRATIONS.

		Page.
1.	The motive power of the Engine	1
2.	Boiler, Single ended return flue	12
3.	Fox corrugated furnace	15
4.	Purves flue	15
5.	Morison suspension furnace	15
6.	Boiler, double-ended	16
7.	,, locomotive	18
8.	,, water tube, "Speedy" (Thornycroft) type ...	21
9.	,, ,, ,, "Daring" (Thornycroft) type ...	24
9a.	,, ,, ,, ,, ,, ,, ,, ...	25
10.	,, ,, ,, tube fire bar ,, ,, ,, ...	27
11.	,, ,, ,, Babcock and Willcox ,, ...	29
12.	,, ,, ,, Blechynden ,, ...	31
13.	,, ,, ,, White ,, ...	33
14.	,, ,, ,, Belleville ,, ...	34
15.	,, ,, ,, Yarrow ,, ...	36
15a.	,, ,, ,, Reed ,, ...	37
16.	Induced draught, Ellis and Eve's system	47
17.	Safety valve	51
18.	Hydrometer or Salinometer	53
19.	Self closing stop valve	56
20.	Feed valve	57
21.	Thornycroft automatic feed arrangement	58
22.	Pressure gauge	59
23.	,, ,, mechanism	60
24.	Compound or combined gauge	61
25.	Vacuum gauge	62
26.	Water gauge, glass	63
27.	,, ,, talc	65
28.	,, ,, automatic shut off valve	64

LIST OF ILLUSTRATIONS.

		PAGE.
29.	Water gauge, glass protector	66
30.	Asbestos packed boiler cock	67
31.	Test cock	67
32.	Hydrokineter	68
33.	Air pressure gauge	70
34.	Armour grating	71
35.	Diagram, oscillating engine	86
36.	,, trunk ,, ...	86
37.	,, return connecting rod engine	86
38.	,, direct acting engine	86
39.	,, simple engine, 2 cylinder	88
40.	,, compound engine, 2 and 3 cylinder	89
41.	,, triple expansion engine	89
42.	,, quadruple expansion engine	90
43.	General arrangement of a four cylinder engine ...	Frontispiece.
44.	,, ,, of steam pipes	93
45.	Separator	95
46.	Condenser	96
47.	,, tubes, fitting ends of	98
48.	Air pump	100
49.	,, ,, valves	102
50.	Centrifugal pump	103
51.	Cylinder liner joints, inner end	108
52.	,, ,, ,, outer end	108
53.	,, and liner and jacket	109
54.	Flat hollow piston	110
55.	Steel piston	111
56.	,, ,, with ramsbottom rings	112
57.	Packing, gland, and neck ring	113
58.	Regulating valve	115
59.	Indicator cocks	116
60.	Piston rod crosshead and guide	119
61.	,, ,, ,, double ended	119
62.	,, ,, ,, return connecting rod	120
63.	Connecting rod and brasses	121
64.	Diagram of turning moments	122
65.	Crank shaft and centrifugal lubricator	124
66.	Plummer block	125
67.	Thrust block	126
68.	Stern shaft and tube with gland	127
69.	,, ,, bracket	128
70.	Refilling worn bearings in place	129

		PAGE.
71.	Refilling worn bearings in place	129
72.	Common slide valve	131
73.	Eccentric strap and rod	132
74.	Angle of advance of eccentric	133
75.	Zeuner's diagram of valve motion	134
76,	Double ported side valve	136
77.	,, ,, ,, ,, with balance cylinder	137
78.	Momentum balance cylinder	138
79.	Cylindrical slide valve	139
80.	Joy's valve gear	140
81.	Reversing motion	142
82.	Link or quadrant	144
83.	Link block	144
84.	*Open* eccentric rods	145
85.	Valve diagram when linked up	146
86.	Expansion of steam	147
87.	Graphical measurement of mean pressure	149
88.	McInnes indicator	151
88a.	,, ,, part section	152
89.	Indicator diagram, actual	153
90.	,, ,, theoretical	153
91.	,, ,, wire-drawing steam	154
92.	,, ,, ,, ,, and exhaust ...	154
93.	,, ,, leaky slide valve	155
94.	,, ,, leaky piston	155
95.	,, ,, ,, ,, ...	156
96.	,, ,, slide valve incorrectly set on rod ...	157
97.	,, ,, angular advance too small ...	157
98.	,, ,, ,, ,, ,, great	158
99.	Indicator diagram, undulation of the indicator ..	158
100.	Measurement of mean pressure	159
101.	Effect of clearance	162
101a.	Loop in indicator diagram	163
102.	Compounded or combined diagrams	164
103.	Weir pump	170
104.	,, Float tank	171
105.	,, Duplex pump	172
106.	Worthington pump, (sectional view)	172
107.	,, ,, front elevation	173
108.	Differential or reversing valve	174
109.	Steering engine	175
110.	,, ,, buffer barrel	177

		PAGE.
111.	Reducing valve	178
112.	Weir evaporater	182
113.	Rayner ,, ...	185
114.	Morison radial evaporator	186
115.	Bye-pass blow down valve	187
116.	Morison feed heater	192
117.	Winch condenser	193
118.	Geddes steam drain trap	195
119.	Evaporators arranged for "double effect"	196
120.	Worthington feed heater	197
121.	Distilling apparatus	200
122.	Feed water filter	202
123.	Syphon lubricator	208
124.	Curve of indicated thrust and speed	212
125.	,, ,, coal consumption and speed	213
126.	,, ,, indicated horse power and speed	213
127.	Feathering paddle wheel	215
128.	Helix formation	217
129.	Common screw propeller	218
130.	Measurement of pitch of screw propeller	221
131.	Bilge ejector	233

CHAPTER. I.

THE MOTIVE POWER OF THE ENGINE.

THE first point to be considered in all engines is, why does the engine move when the pressure is admitted to the cylinder? To show this experimentally get a parallel glass tube with a moderately tight-fitting piston, which we will consider weightless. The bottom end of the tube is closed. Take out the piston and put in a little water, say about ¼ inch in depth and then replace the piston which rests on top of the water. The water is at a temperature of about 62 degrees. The tube is now warmed until a temperature of about 212 degrees is reached, and by this time the piston will have risen very slightly as shown in the middle figure. The water has expanded slightly, due to the rise of temperature. At the temperature of 212° the water begins to boil and steam being formed the piston will rise considerably. This is due to the steam being of much greater volume than the water from which it is formed. If all the water be evaporated the piston will rise to a height equal to 1770 times the original depth of the water. Consequently water expands 1770 times when converted into steam under the normal pressure of the atmosphere. Now apply a pressure on top of the piston, and compress the steam, and on relieving the pressure the piston will rise to its original height. That is to say, that compressed steam has a force in itself, and will react on the piston exactly in proportion to the original pressure used to compress it. Suppose the area of the piston is two square inches and the

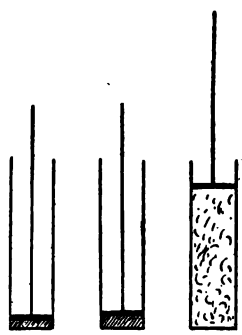


Fig. 1.

total force applied had been 100 lbs. Then on each square inch a force of 50 lbs. has been exerted. This pressure acts in every direction, and if the tube is not strong enough it will burst it, or the bottom might be blown out. This is exactly what happens in the cylinder of an engine. The sides and covers resist the pressure, and the piston not having sufficient external force to resist the pressure, moves in the direction of the weaker resistance. Suppose a weight is placed on the piston of 60 lbs. Then the pressure per square inch on the piston will be 30 lbs. on one side and if there be 50 lbs. on the other, the piston will commence to move upwards with a pressure of 20 lbs. (the difference) per square inch of piston.

In the steam engine the piston takes steam on each side of the piston alternately. Considering one stroke or in other words the piston only moving in one direction; then the steam from the boiler will be pressing the piston on one side, and the exhaust steam side which is open to the atmosphere or condenser, will be exerting a pressure or resistance on the other, so that the boiler steam has to overcome the resistance.

For example, the boiler pressure is 50 lbs. per square inch and the exhaust pressure is 10 lbs. per square inch, then the actual pressure to overcome the resistance of the engine is, $50-10=40$ lbs. per square inch. For practical purposes of rough calculation the pressure of steam in a closed vessel varies inversely as its volume. So that if 20 cubic inches of steam at 10 lbs. pressure were compressed into 5 cubic inches, the pressure will rise to 40 lbs.—

Or, $$\frac{20\times 10}{5}=40$$

This is what goes on in a boiler. The water is evaporated and as the steam is made it is compressed having only about the same space to fill and therefore the pressure rises. If the

absolute pressure is 60 lbs. in the boiler it means that the steam has been compressed into about one-sixtieth of the room it might occupy at 1 lb. *absolute* pressure.

The very small volume of water required to make a very large volume of steam shows the great expansive power of water when evaporated, and places it in the first place among the means of exerting force.

It has been proved by experiment that water heated in a vessel open to the atmosphere boils at a temperature of 212° (Fahrenheit). But if the vessel is closed and evaporation continues so that the pressure is increased it is proved that the temperature will rise also. Similarly if the pressure be decreased so as to be below the pressure of the atmosphere the temperature decreases also. The annexed table gives these corresponding temperatures of various pressures together with various other peculiarities of the properties of steam which will be considered later on.

STEAM:

ABSOLUTE PRESSURE, TEMPERATURE, VOLUME, AND DENSITY.

Absolute Pressure in Pounds per Square Inch.	Temperature, Fahr.	Total Heat from Water at 32 Degs.	Volume of One Pound in Cubic Feet.	Density or Weight of One Cubic Foot.	Absolute Pressure in Pounds per Square Inch.	Temperature, Fahr.	Total Heat from Water at 32 Degs.	Volume of One Pound in Cubic Feet.	Density or Weight of One Cubic Foot.
1	102.1	1112.5	330.36	.0030	70	302.9	1173.8	6.07	.1648
2	126.3	1119.7	172.08	.0058	75	307.5	1175.2	5.68	.1759
3	141.6	1124.6	117.52	.0085	80	312.	1176.5	5.35	.1869
4	153.1	1128.1	89.62	.0112	85	316.1	1177.9	5.05	.1980
5	162.3	1130.9	72.66	.0138	90	320.2	1179.1	4.79	.2089
6	170.2	1133.3	61.21	.0163	95	324.1	1180.3	4.55	.2198
7	176.9	1135.3	52.94	.0189	100	327.9	1181.4	4.33	.2307
8	182.9	1137.2	46.69	.0214	105	331.3	1182.4	4.14	.2414
9	188.3	1138.8	41.79	.0239	110	334.6	1183.5	3.97	.2521
10	193.3	1140.3	37.84	.0264	115	338.	1184.5	3.80	.2628
11	197.8	1141.7	34.63	.0289	120	341.1	1185.4	3.65	.2738
12	202.	1143.	31.88	.0314	125	344.2	1186.4	3.51	.2845
13	205.9	1144.2	29.57	.0338	130	347.2	1187.3	3.38	.2955
14.7	212.	1146.1	26.36	.0380	135	350.1	1188.2	3.27	.3060
15	213.1	1146.4	25.85	.0887	140	352.9	1189.	3.16	.3162
16	216.3	1147.4	24.32	.0411	145	355.6	1189.9	3.06	.3273
17	219.6	1148.3	22.96	.0435	150	358.3	1190.7	2.96	.3377
18	222.4	1149.2	21.78	.0459	155	361.	1191.5	2.87	.3484
19	225.3	1150.1	20.70	.0483	160	363.4	1192.2	2.79	.3590
20	228.	1150.9	19.72	.0507	165	366.	1192.9	2.71	.3695
21	230.6	1151.7	18.84	.0531	170	368.2	1193.7	2.63	.3798
22	233.1	1152.5	18.03	.0555	175	370.8	1194.4	2.56	.3899
23	235.5	1153.2	17.26	.0580	180	372.9	1195.1	2.49	.4009
24	237.8	1153.9	16.64	.0601	185	375.3	1195.8	2.43	.4117
25	240.1	1154.6	15.99	.0625	190	377.5	1196.5	2.37	.4222
30	250.4	1157.8	13.46	.0743	195	379.7	1197.2	2.31	.4327
35	259.3	1160.5	11.65	.0858	200	381.7	1197.8	2.26	.4431
40	267.3	1162.9	10.27	.0974	210	386.	1199.1	2.16	.4634
45	274.4	1165.1	9.18	.1089	220	389.9	1200.3	2.06	.4842
50	281.	1167.1	8.31	.1202	230	393.8	1201.5	1.98	.5052
55	287.1	1169.	7.61	.1314	240	397.5	1202.6	1.90	.5248
60	292.7	1170.7	7.01	.1425	250	401.1	1203.7	1.83	.5464
65	298.	1172.3	6.49	.1538	260	404.5	1204.8	1.76	.5669

CHAPTER II.

DEFINITIONS AND UNITS.

A bounded part of matter is called a body, and the part of space which a body occupies is called its *volume*. The amount of matter contained in a body is called the *mass* of the body. In practice the standard of mass is called a pound.

Length.—The standard of length is a *yard*, but in engineering the *unit* of length is one-third of a yard or one *foot*.

Time.—Time is a consequence of motion; if there were no motion there would be no time. The unit of time is a *second*.

Density.—By the density of a substance, is understood the mass contained in one unit of volume of the substance. The density of a substance varies with the temperature and the pressure to which it is subjected.

Specific Gravity.—By relative density, or specific gravity of a substance, is understood the ratio of the density of the substance to that of pure water at a standard temperature. This temperature is often taken at 39·1° Fahrenheit, this being the temperature of the maximum density of water. The relative density of a gas is usually taken as the ratio of the density of the gas to that of air at 32° Fahrenheit, and at a pressure of one atmosphere.

Specific Volume.—By specific volume or bulkiness of a substance, is understood the number of units of volume occupied by a portion of the substance, of which the mass is equal to the standard mass. *It is measured by the number of cubic feet to the pound.*

Force.—A body which is at rest—*i.e.*, remaining at the same place in space—cannot change its place without a cause. Nor can a moving body change the conditions of its motion without a cause. Such cause is called *force*. The engineering unit of force is the force that can balance the weight or mass of 1 lb. at sea level at Greenwich. This force is called a pound, or the pound weight. A force which acts upon a moving body in the direction of the motion of the body is called an *effort*, and a force which acts opposite to the direction of the motion is called a *resistance*.

Velocity.—A moving body which is not acted upon by any force, or is acted upon by forces which are mutually balanced, will pass through equal spaces in equal times. Such motion is called *uniform* motion, and the ratio of length of space passed over to the corresponding length of time is called the velocity of motion, or the rate of motion. If the moving body be acted upon by one force, or by several forces which are not mutually balanced, the length of space passed over by the body in equal times will vary, and such motion is called *variable* motion. The motion may be *accelerated* or *retarded* according to whether the force is an effort or a resistance. The velocity of such a body at any given time is the velocity the body would have, if the force or forces, suddenly ceased to act, the motion then being uniform.

The *unit of velocity is one foot per second.*

Work.—Producing motion against resistance is called work. The product of the resistance in terms of unit of force, and the distance in terms of unit of length, through which it has acted is therefore a measure of the work done on the resistance.

The *unit of work is one foot—pound.*

Power.—It is not only necessary to know what work a machine has to do, but we must also know within what time it must perform the work. By the power of an engine, we, therefore, understand the rate at which it can do work—*i.e.*, the quanity of work which it can do in a certain interval of time. The *unit of power is one—foot—pound—second.* But as this unit is small, it is more convenient to use a derived unit of power. In engineering this is one *horse-power*, which is equal to 33,000 foot-pounds per *minute.*

Energy.—The capacity of bodies for doing work is called energy, and a body is said to contain more energy the more work it can do, regardless of time. The terms energy and power must not be considered to mean the same. Power has relation to time. Thus one ton of coal can by being burned in a sufficiently large boiler, produce steam for developing, say, 700 horse power in one hour; whereas, when being burned in a small boiler, it can produce 50 horse power for 14 hours. (The efficiencies of the boilers and engines are assumed to be the same)

Energy appears under various forms:—thus mechanical energy, heat, electrical energy, etc., but they are all convertible. Energy cannot be created or destroyed; this statement is expressed in the principle of conservation of energy, and also in the impossibility of perpetual motion.

Work represented by an area.—As work and energy exerted are products of two quantities, force and length, they can be represented by the area of a plane figure, which is also the product of two quantities. This is practically applied for measuring the work done in engines by graphical means for which the Indicator is used. (See chapter XI. The Indicator and Indicator diagrams).

Efficiency.—In every mechanism there is a certain amount of waste so that the actual work obtained does not reach the

actual power expended.—The efficiency of the machine is represented by a ratio or fraction:—

$$\text{Efficiency} = \frac{\text{Useful work done.}}{\text{Total power expended.}}$$

In marine propulsion there are four elements which each absorb a certain portion of the total power, these elements are the boiler, the steam, the mechanism and the propeller. Therefore the *Total Efficiency* of the marine steam engine is represented by the *products* of the four efficiencies of the four elements. So that the only manner in which economy can be gained is by an improvement in one of the four efficiencies.

Temperature of a body is measured in degrees on the Fahrenheit scale, that is, the difference in temperature between water at freezing point and boiling point, under normal atmospheric pressure is divided into 180 parts called degrees of temperature. The scale is taken downwards 32 degrees and this is the zero of the Fahrenheit scale. Thus, fresh water freezes at a temperature of 32° Fahrenheit, and boils at a temperature of 212° under normal atmospheric pressure.

The amount of heat required to raise one pound of water at its maximum density, (39·1) one degree is called a *thermal unit*, and for practical purposes in this book may be considered constant at all temperatures.

Heat and work are mutually convertible, and by experiments it has been proved that one thermal unit will produce 772 mechanical units of work, or 772 foot-lbs. And conversely 772 foot-lbs. of work can be converted into one thermal unit. In other words, that the heat necessary to raise the temperature of one pound of water one degree in temperature (from 39° to 40° Fahrenheit) can be made to perform the work of raising 772 lbs. one foot high. The expression 772 is frequently represented by the letter J and is called *Joule's equivalent.*

Sensible Heat.—It is found by experiment that the heat required to raise a lb. of water to the point of evaporation varies with the pressure on the water. The heat thus used is called the sensible heat, and is that required to raise the temperature to the point of evaporation only.

Latent Heat.—After the temperature of evaporation is reached it is found that the temperature does not rise (the pressure remaining constant) and that a considerable amount of heat has to be expended in converting the water into steam. This is called the *latent heat* of steam and at atmospheric pressure is represented by 966 thermal units. In other words Latent heat is the amount of heat required to change a body from a given state into another state, without altering its temperature.

If after all the water is evaporated, heat be still added, the steam becomes super-heated and the temperature rises.

Total Heat of Evaporation is thus equal to the sum of the sensible and latent heat, or:—

$$H = L + S, \text{ where}$$

H is the total heat of evaporation,
S is the sensible heat,
L is the latent heat. Now let T be the temperature of evaporation and t = temperature of the water originally.

Then $S = T - t$; and it is found from experiment that,
$L = 966 - 0{\cdot}7\ (T - 212)$ approximately,
Therefore, $H = 1114 - 0{\cdot}7T + (T - t)$
$= 1114 + 0{\cdot}3T - t$

From this it will be seen that as T increases S must also increase; and, that as T increases, L must decrease; but that as T increases, H must also increase. So that if the pressure be increased, and consequently the temperature of evaporation increased the total heat of evaporation will increase.

Taking the temperature of the feed water for a boiler to be about 100° which is a common practice.

Then, $H = 1114 + 0{\cdot}3T - 100$
$= 1014 + 0{\cdot}3T.$

The *absolute temperature* of the air thermometer is measured from a zero which is 461° below the zero of the Fahrenheit thermometer. Example, the absolute temperature of the boiling point of fresh water under atmospheric pressure would therefore be represented by,

$$461 + 212 = 673.$$

The *absolute pressure* is measured from the zero pressure of the atmosphere, and is usually taken as 14·7 lbs. per square inch below the mean atmospheric pressure when the mercury barometer stands at 30 inches.

The *pressure* guage shews only the pressure above that of atmospheric pressure, the *vacuum* guage shews the pressure below atmospheric, and is graduated to 30 inches, this being the equivalent of a column of mercury on the barometer. The higher the vacuum the less the absolute pressure, thus at zero on the vacuum guage the absolute pressure is 14·7 lbs. on the square inch (or the pressure due to the weight of the atmosphere), and is the same as the zero on the pressure guage. When the vacuum gauge registers 26 inches, the absolute pressure is about 2 lbs. per square inch. A compound guage shows both pressure and vacuum, the first in lbs. and the latter in inches of mercury. It would be a great convenience if all pressures were measured from the *absolute* zero instead of the *atmospheric zero.*

The relation between temperature and pressure is given by the following very approximate formulæ

For pressures between 50 lbs. and 350 lbs. absolute

$$T = 223 + 0{\cdot}277 \sqrt{(2113 - P)(P - 29)}$$

where T = temperature

and P = absolute pressure.

For pressures below 50 lbs. absolute use,

$$T = 138{\cdot}3 + 1{\cdot}389 \sqrt{(279 - P)(P - 3{\cdot}9)}$$

This is a formula of large dimensions but is given for calculations which may be required, and as a reference.

CHAPTER III.

THE BOILER.

A BOILER is a closed vessel containing partly steam and partly water. Steam is produced by applying heat to the water, by which the temperature of the water rises, becoming greater and greater as more heat is added. It is only one part of the heat, the *sensible heat* which is spent in raising the temperature of the water; the rest of the heat, the *latent* heat is spent in changing the water into steam-gas. Therefore starting with cold water in the boiler the heat generated by the fire, will first raise the temperature to a point when evaporation commences, and the temperature will stop at this point until steam is formed, and a pressure obtained. The temperature then slightly increases as the pressure rises, but if the pressure is maintained at a certain point the temperature will also be maintained at a corresponding point. Therefore when the safety valves are blowing off steam, although more heat is added the temperature remains constant at a point corresponding with the pressure or load on the safety valves.

The old form of boilers was simply a square box, with furnaces, sometimes as many as six to one boiler, contained within the box. These boilers worked at pressures ranging from 5 to 40lbs. At this last pressure, the stays from side to side, front to back and vertically, became so close together that access to the interior was almost impossible, and consequently the boiler took a circular shape for its shell with flat front and back. The front and back of the circular boiler require considerable staying, but the stays running parallel to each other and not being crossed, access is obtainable for cleaning

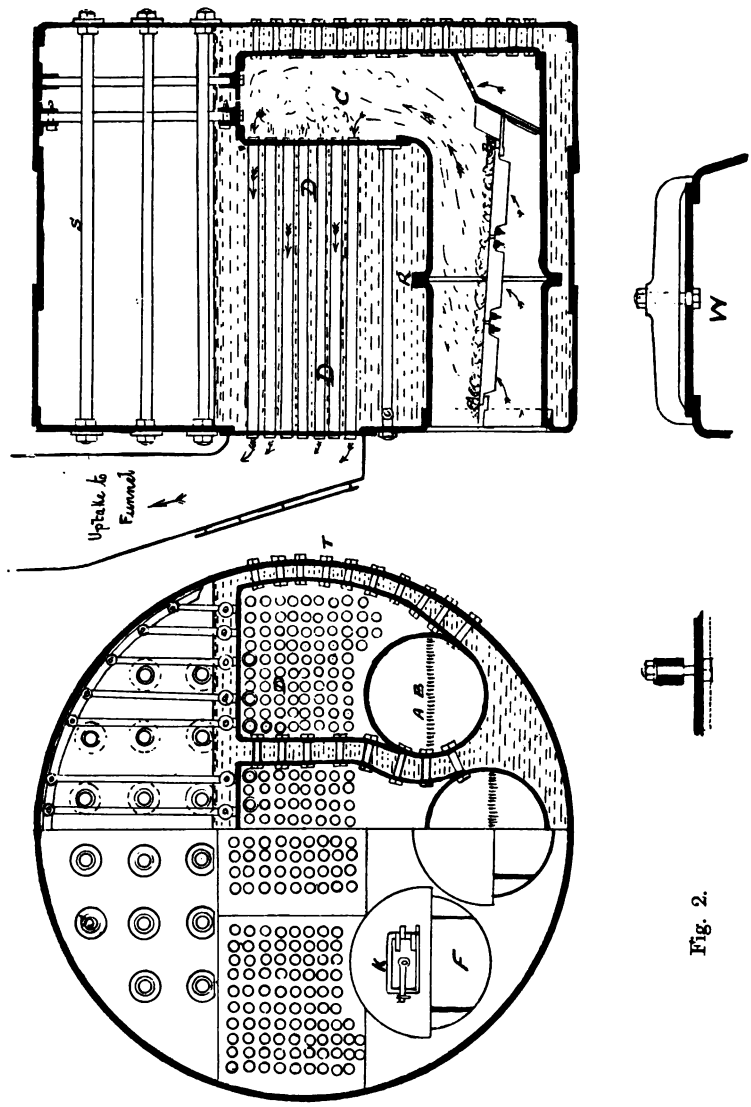


Fig. 2.

and examination; and the circular "shell" or tank boiler has been adapted for pressures of 180 and 200lbs. above the atmosphere. A type of this boiler is shewn in fig. 2., A.B. is the fire grate inside the furnace, C is the combustion chamber,

D.D., the heating tubes leading from C to the chimney through the smoke boxes and uptake.

The boiler is filled with water to a few inches over the top of the combustion chamber C. The fire is then lighted on the fire grate A.B, and the furnace door K closed; air for the combustion or burning of the coal being supplied through the ash pit door F, which allows it to pass under the fire grate AB, and then find its way through the fire. The burning gases escape into the combustion chamber C, and then through the tubes DD, into an external casing at the bottom of the uptake, to the chimney or funnel.

The furnace, combustion chamber and tubes are heated by the flames, and these in turn communicate their heat to the water which surrounds them all, and thus the steam is generated from the water and eventually fills the space above the water level and is compressed in it.

To withstand the pressure the outer shell is made circular as shewn but the ends being flat are stayed together to prevent bursting, this is effected by the long stays S. The furnace is also made round to prevent collapse, from the external pressure and is frequently in addition strengthened by ring flanges, and generally for high pressures, one of the types of corrugated furnaces shewn in figs. 3, 4, 5, is used. The combustion chamber requires many stays and these take various forms, the stays marked T, are called screwed stays because they secure the combustion chamber to the outer shell, by means of long screws with nuts at each end. These stays are fitted between the combustion chambers and round the shell, being generally pitched at a distance not greater than nine inches from each other. The front or furnace end of the combustion chamber, is stayed by some of the tubes being screwed at the ends, and in this way staying, both the front of the combustion chamber and the front tube plate;

sometimes solid stays are used for this work. The top of the combustion chamber is secured to the outer shell, by means of solid bars, as shewn, the ends being jointed and forked, and pinned to an angle iron riveted to the shell, and to screws screwed through the top plate with nuts on the under side. Sometimes *dog stays* are used, similar to the one shewn in sketch, W, these are useful as they give access through the stays and over the top of the combustion chamber.

Furnaces.—In flame tube boilers it was found as pressures increased, that the furnace plates required, when the furnace was a plain hollow cylinder, to be made of too great thickness. This increase of thickness, involved a greater weight, and a loss due to a lower *rate of conduction* of heat. As the furnace absorbs over three-fifths of the heat given up to the water, this became a somewhat serious loss. To obviate this, various methods were adopted, for increasing the strength against collapsing, and they generally took the form of the Adamson ring shewn in fig. 2. The "Fox" corrugated furnace, shewn in fig. 3, was then introduced and gave good results. As will be seen, on reference to the figure, it consists of a series of uniform corrugations, the plate being of uniform thickness throughout. In practice it is found that the lower part of the corrugations, i.e., those next the fire, absorbed most of the heat, while the upper parts absorbed comparatively little, and the corrugations caused an appreciable retardation of the flames passing into the combustion chamber. On the water side of the furnace, scale accumulates on the lower parts of the corrugations, and is difficult to remove, and from this cause the theoretical evaporation of the furnace is much reduced in practice.

The Purves flue, shewn in fig. 4, to a certain extent reduces these objections to a minimum, but as will be seen from the figure the section is not of uniform thickness, being some-

what thicker at the corrugations. It is thought by some engineers that this variable thickness, produces variable strains and may produce cracks in the furnace.



Fig. 3.



Fig. 4.

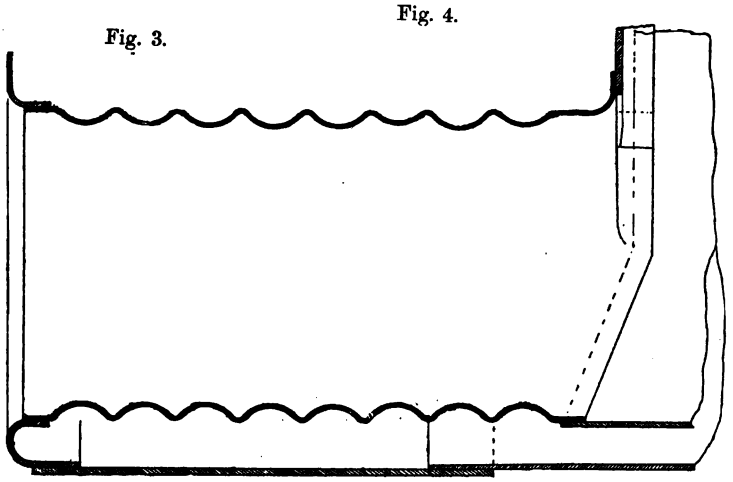


Fig. 5.

Fig. 5 shews the Morison suspension furnace; this is very similar to the "Fox" furnace, but the corrugations are longer and flatter, and therefore more easily cleaned. The section is of uniform thickness throughout, and as arranged in the sketch the furnace can be removed, without disturbing any other part of the structure of the boiler. Similarly to the Purves flue, it offers little resistance, to the passage of the flames and gases to the combustion chamber. In section the form of the suspension furnace is very similar to a catenary paraboloid. The pitch of the corrugations in the "Fox" furnace is about 6 inches, and the depth $2\frac{1}{2}$ inches, or a difference of 5 inches between the greatest external diameter, and the least internal diameter.

In the Purves flue the pitch is 9 inches, and depth 2 inches

In the Morison suspension furnace the pitch is 8 inches, and depth 2 inches.

The efficiency of the flame tube boiler depends to a very great extent on the efficiency of the furnaces, and consequently the surfaces, both internal and external, should always be free from any scale whether of grease or lime. It has been computed by experiment, that the rate of conduction through a plate, on which a scale of grease of only one sixty-fourth of an inch has been deposited, is decreased by about the same amount, as that due to about one eighth of an inch of ordinary clean lime scale. In a boiler, which is well and efficiently worked, it is usual to find that the furnaces internally, (water side) are quite bright and clean, and this can always be effected by proper attention to cleaning the boiler, at every opportunity, and by reducing the oil, used for internal lubrication of the engines, to a minimum.

When the tubes are placed as in figure 2 the boiler is termed a return-tube or return-flue boiler. Boilers of this type are the most common in use, and sometimes when placed

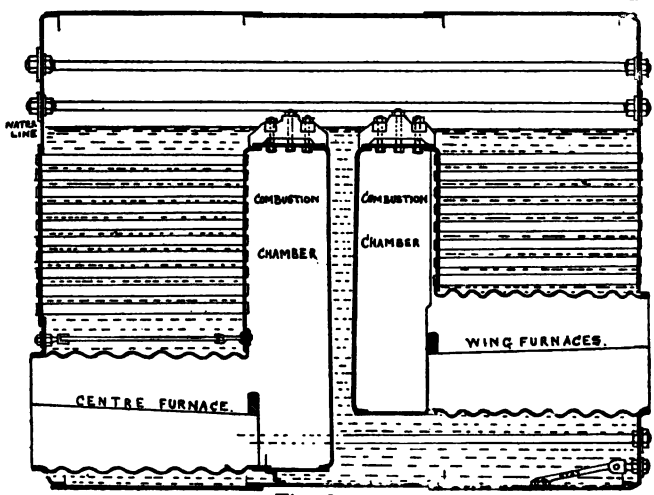


Fig. 6.

back to back and made in one, take the form known as the *double ended boiler* shewn in fig. 6. This boiler is fired from each end. The method saves the weight of the end plates, and sometimes only one combustion chamber *common* to *all* furnaces, has been fitted. The common combustion type of double ended boiler, is not a successful one in actual working, as the abolition of the water spaces between the several combustion chambers, has stopped circulation to such an extent, that over heating of the tube plates and tube ends has taken place with disastrous results. They are now generally fitted with a separate combustion chamber, for each furnace, as shewn in the figure. The slight increase in weight is soon saved in economy of working. The single ended return-tube boiler is probably the most reliable of all flame tube boilers. Either single or double ended return tube boilers have generally been fitted in large ships.

Where the height is small, *direct-tube* boilers have been fitted. The shape is cylindrical, and the tubes are on the same level horizontally with the furnace. This type of boiler gave very good results in actual working, as much as 10 lbs. of water being evaporated per 1 lb. of coal burnt. There are generally two or three furnaces, and sometimes separate common combustion chambers are fitted.

Locomotive Boiler :—This boiler takes its name from its similarity in form to that of an express boiler. It is a *direct tube* boiler, the flames passing direct through the tubes, into the funnel, which is at the back end of the boiler. For high speed vessels its use was almost universal, until the introduction of the water-tube boiler. It is still a boiler which is used, but will probably soon be entirely superseded by water-tube boilers. The fig. 7 shews the type known as the wet bottomed locomotive boiler. There is one large furnace only, but it is almost divided in this particular instance, into

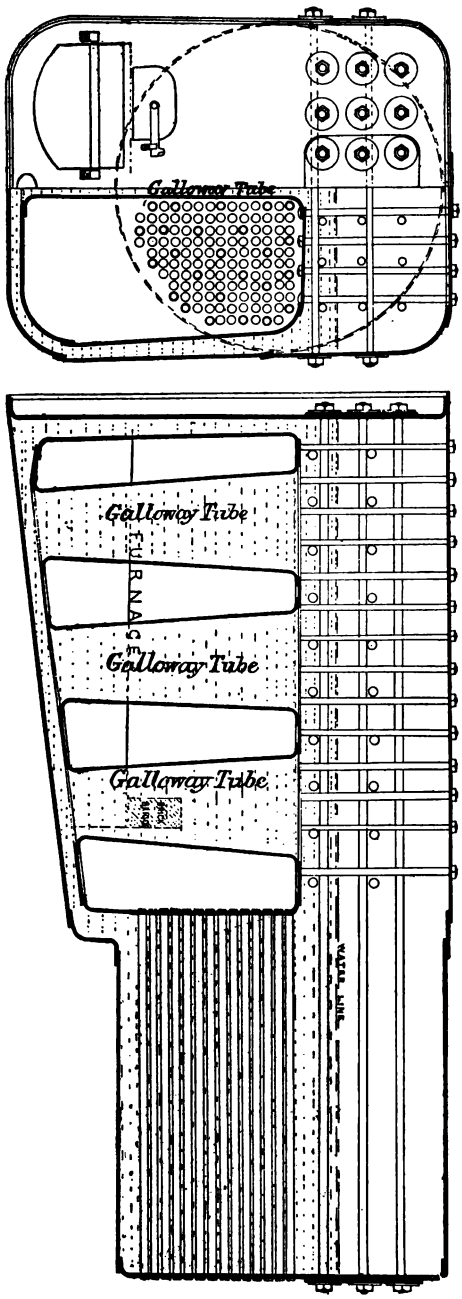

Galloway Tube
Galloway Tube
FURNACE
Galloway Tube
Galloway Tube
WATER LINE

Fig. 7.

two parts, by three galloway tubes. Galloway tubes are not universal in this type, but there is no doubt that where they have been fitted they have more than justified their existence. The slight decrease in grate surface is more than compensated for by increased heating surface, and better circulation. The tops or crowns of the furnaces, in the locomotive type of boiler, are almost flat and horizontal, and consequently when the boiler is forced the generation is very rapid on these surfaces. Without galloway tubes or some other means of supplying water quickly in place of that evaporated, it is possible that the surface of the crowns may be occasionally boiled dry, and although this is probably a very extreme case the tendency is in this direction. Fresh cold water moves to take the place of that evaporated, and violent ebullition ensues with possibly *priming*. The galloway tubes supply water which is already partially heated, and the supply being continuous assists in maintaining a constant water level.

There is probably nothing in engine driving more difficult to combat than *priming*, when it is due to faulty design of the boiler or its fittings. The engines must be eased when it occurs, or an accident of the worst description may occur in the engine room.

It will be seen from the figure that there must be a great number of stays fitted vertically and horizontally, owing to the flat sides of the boiler. In addition to those shewn screwed stays are fitted, pitched at $4\frac{1}{2}$ in. to 5 in. apart, all over the sides and front, and in the galloway tubes of the furnace. Also at certain parts of the bottom of the furnace, and at the junction of the furnace and the back end of the boiler, screwed and other stays are fitted. All this staying renders the boiler very inaccessible for cleaning purposes round the furnaces, which form as in all boilers, the most efficient part of the heating surface.

The tubes in this type of boiler, are generally from $1\frac{1}{2}$ in to 2 in. in diameter, and a certain number are made of thicker material to serve as stay tubes. These stay tubes are shewn in the left-hand figure.

As much as 70 to 80 lbs. of coal, can be burnt in the locomotive boiler per square foot of grate, and perhaps for this reason the evaporative results are so good. Whether such a large quantity of coal can be burnt efficiently, is not stated, and it is very doubtful. Probably the flaming at the funnels is due to this cause, as a certain amount of carbon mon-oxide bursts into flame on reaching the outer air, when the temperature is sufficiently great. When forcing it is a comparatively easy matter to obtain the requisite temperature. If flaming is to be prevented more grate surface must be given, and more air supplied to the fire.

Water tube Boilers.—This type of boiler has been well known to steam users for many years. It was the first high pressure boiler invented, but until recently the exorbitant price owing to the small demand for the requisite materials, has prevented its coming into general use. Materials, however of the requisite strength and cheapness, are now forthcoming, and in a few years it is probable that no other kind will be manufactured. The demand for higher pressures, together with the difficulty of building boilers of the flame tube type for pressures over 200 lbs. renders it imperative that such a change should take place, During the past few years many hundreds of boilers of the water tube type have been patented, and it would be difficult to enumerate them all. Undoubtedly the original boiler of Mr. Loftus Perkins was the pioneer of the water tube boilers, now so extensively used, and the latter ones are merely a growth of his original experiments, and modifications of others of later date.

Figure 8 shews sectional elevations of the **Thornycroft "Speedy"** type ofwater tube **boiler.** This has been in use for

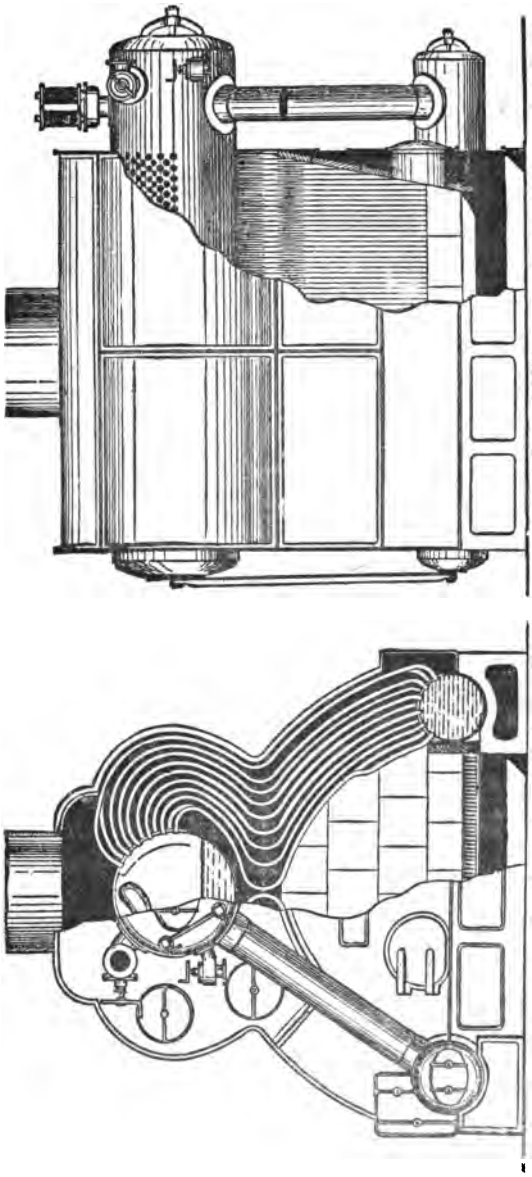


Fig. 8.

many years, and has given good results. The top tube forms a steam and water chamber, into which the small generating tubes deliver steam and water mixed, continuously. The steam is separated out, and the water drops to the bottom of the chamber. The water is then carried down by two large pipes, outside the furnace, to the two lower main tubes or water chambers. From these water chambers the water is circulated, through the generating tubes, back into the separator or top main tube. The generating tubes deliver their contents above the normal water level, and this makes a continuous flow or circulation in one direction.

Mr. Thornycroft estimates that a particle of water is delivered into the top separator tube, over a hundred times, before being taken off as steam.

Further experiments proved, (see Records of Inst. of N. A. 15 March, 1894), that a continuous and rapid circulation, in boilers of this type, prevents the formation of scale, and this appears to be borne out in practice, for, the generating tubes have the appearance of being thoroughly clean after continuous working; the grease and other solid matter gravitates into the bottom of the water chambers from which it can be washed out with a hose. The circulation is about twice as rapid with above water discharge tubes, as with tubes in which the top ends are submerged, and this detracts in a great measure from the latter keeping clean and free from scale. Having a continuous and rapid circulation, in one direction, obtained in a natural manner by the heating of the tubes and the constant supply from the separator through the down-takers, this boiler is the nearest approach to the ideal boiler or steam generator.

A continuous circulation is almost a necessity, as well as an economy, for, with an alternating circulation, the tubes are liable to overheating by a sudden change of direction of circulation, or a temporary stagnation.

Copper loses a great part of its tenacity at a temperature of only 600° Fahrenheit, and when using high pressures corresponding to temperatures of 400° Fahrenheit, the difference is not very great between the two temperatures. It is probably due to this fact that accidents have happened when copper tubes have been used. Mild steel, generally covered with a very thin coating of zinc, is now used for all Admiralty work, and, where copper has been fitted, steel is being substituted. All the Thornycroft boilers are built of steel throughout.

The very large space above the fire in water tube boilers is very advantageous to complete combustion of the furnace gases. This is made of the greatest utility in the "Daring" type. Care must be taken however that this space is left free for this purpose by proper stoking, for with badly trained stokers *flaming* may be produced by using a thick fire. A thick fire prevents the proper supply of air for complete combustion.

Normand Boiler:—This is very similar to the Thornycroft "Speedy" type. The exit to the funnel is retarded by a partial screen of water-tubes, fitted at about one third the length of the boiler from the back end. The generating tubes deliver their contents both above and below water, about four rows of tubes delivering above the working water level.

The upper main tube, or separator, is about three feet in diameter, and the lower, or water chambers are about 18 inches in diameter. The feed is pumped into the lower chambers, which are connected by a tube at the back end. There are two down tubes in front, each about 8 inches in diameter, and one at the back, about 3¼ inches diameter, which joins the connecting tube above mentioned. No stay tubes are required. The boiler including the generating tubes is built of steel throughout. The generating tubes are about 1¼ inch in

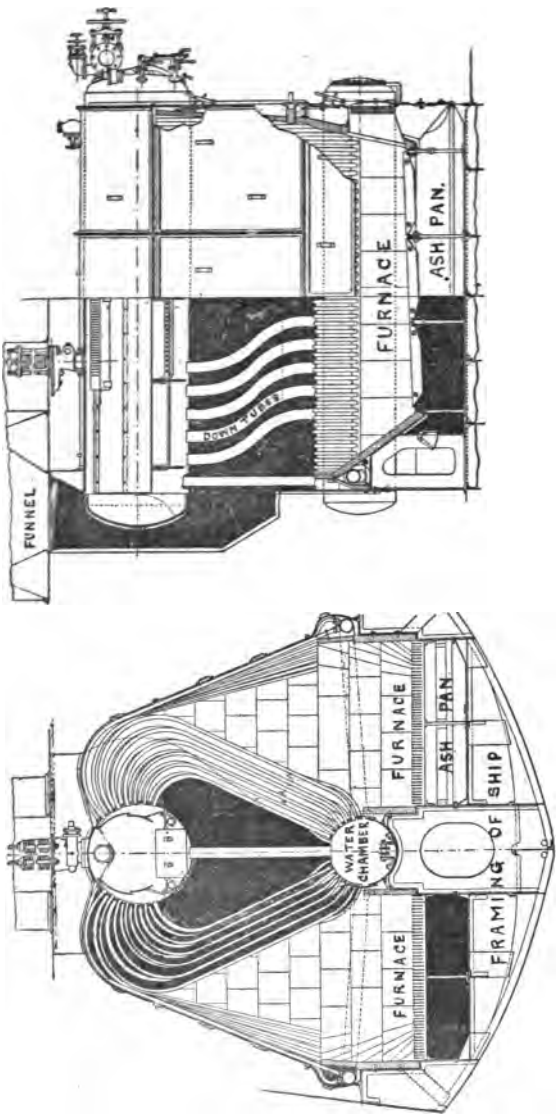

FUNNEL
FURNACE
ASH PAN.
WATER CHAMBER
FURNACE
ASH PAN
FURNACE
FRAMING OF SHIP

Fig. 9.

diameter, and rather over a tenth of an inch thick. The indicated horse power per square foot of grate surface, is somewhat higher than in some other types, but this is probably

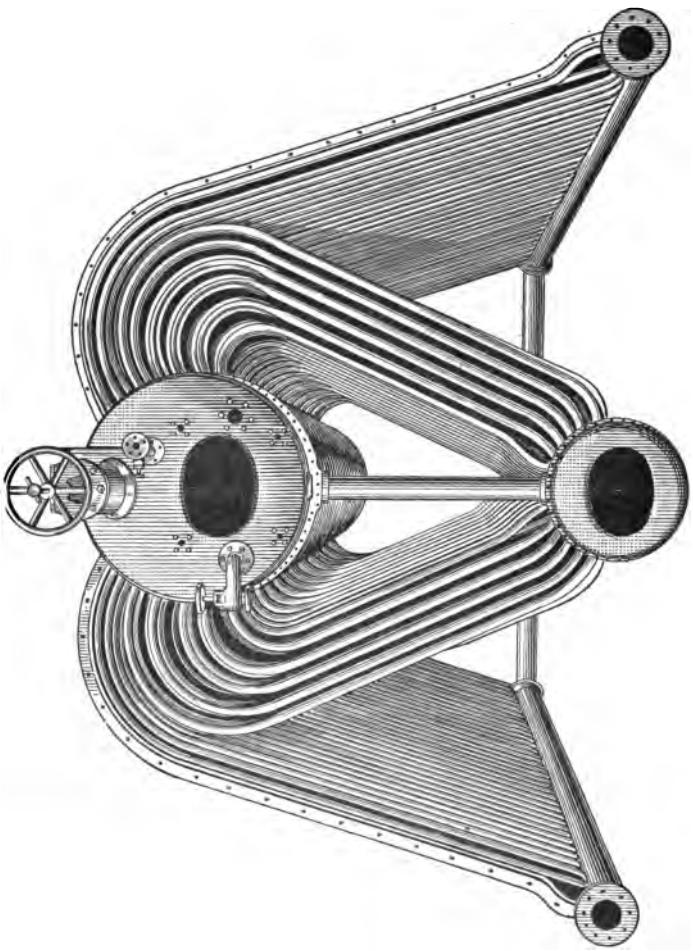
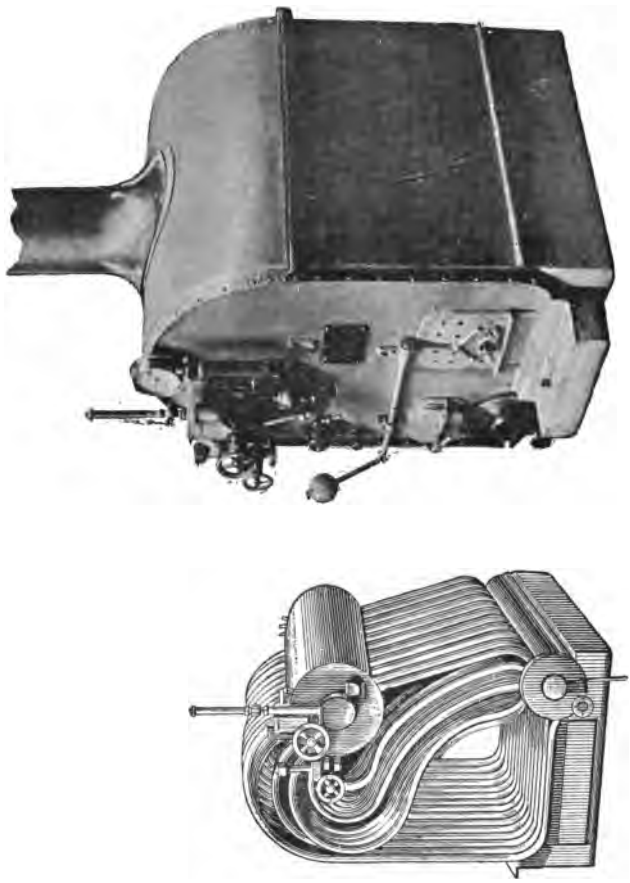


Fig. 9a

due more to economy of engines than that of boilers. There is a comparatively large heating surface. No automatic feed arrangement has been fitted.

The **Thornycroft "Daring" type of water tube boiler,** is shewn in figs. 9 & 9a. It has four main tubes, one above and three below. The top main tube, or separator, is filled with steam and water. The water level is just *below* the entrance of the generating tubes into the separator. The two spaces formed by the three water chambers, or lower main tubes, form the furnaces, the grate being on a level with them, with the ash pans underneath.

The middle water chamber is of sufficiently large diameter to admit of having a man-hole door fitted at the end thus giving easy access to the generating tubes, which are expanded in the usual way to make them water and steam tight. The wing water chambers, are of about 4 to 6 inches internal diameter, and the generating tubes are expanded in the usual way by means of an ingenious contrivance, which can be manipulated from the stokehold platform. Two rows of tubes are fitted into each wing water chamber, and bent in such a way that they form a complete wall on the outside of the furnace, being bent again when entering the separator tube. In the later boilers of this type, other rows of tubes are added to these and give good results. Each wing water chamber is continued round the back of the furnace, behind the brickwork, and joins the centre water chamber. Several tubes of large diameter (four inches) connect the separator tube with the centre water chamber, these are termed the down-takers as they keep up the supply of water for the whole of the generating tubes. The feed water is pumped into the separator just below the working level. This boiler has many advantages especially in lightness and efficiency, and can be forced to any extent without detriment to the boiler. Nearly the whole of the ground space occupied can be used as grate surface. Any generating tube can be taken out, and renewed without moving any fixtures, or the holes can be plugged. The boilers in some



Figs. 10.

destroyers are fitted up piecemeal in the ship, and all the generating tubes subsequently fitted and expanded in place. This is a great gain in itself. The generating tubes are from one inch and an eighth, to one inch and a quarter in diameter. The indicated horse power developed per ton of boiler, mountings, etc. (including funnels, and all the usual gear in

connection with the boilers), is about one hundred; with locomotive boilers it would be only about 35 I.H.P. per ton of boiler.

Another type of boiler of the Thornycroft family is that shewn in fig. 10. Messrs. Thornycroft have had one in use for some months, working with river water, and no scale has been found in the tubes. The special points are that there is only one upper and one lower main tube, and the generating tubes are bent in such a way as to form the fire bars of the furnace. The generating tubes deliver above water, and the usual down-takes are fitted. About 100 I.H.P. is developed per ton of weight complete, a remarkable performance for a small boiler. Water-bars are not unknown, but hitherto have not proved very successful. In this type however they appear to have worked well, as after six months continuous working the zinc on the water bars was uninjured. With a good and continuous circulation it is hard to conceive how any harm should result from the fire being on them. The only objection appears to be from careless use of fire irons, and as the tubes are very strong being drawn down in diameter, and consequently considerably thickened where they form the grate, an accident from this cause is very improbable. At any time the small generating tubes, in a water-tube boiler have an enormous margin of strength, and in this case the margin has been considerably increased.

The **Babcock and Willcox** boiler, shewn in fig. 11, consists of a number of lap-welded iron tubes, placed in an inclined position, the ends being connected at the front, as well as at the back, to the main separator or top tube by two sets of tubes. The end connections are in one piece for each vertical row, and are so placed that the tubes, in the same horizontal

row, come over the spaces left between the tubes in the row below. The holes in the end connections are connected with the main shell by tubes, and at the back also with a mud-drum below. A mud-hole is placed opposite the end of each tube.

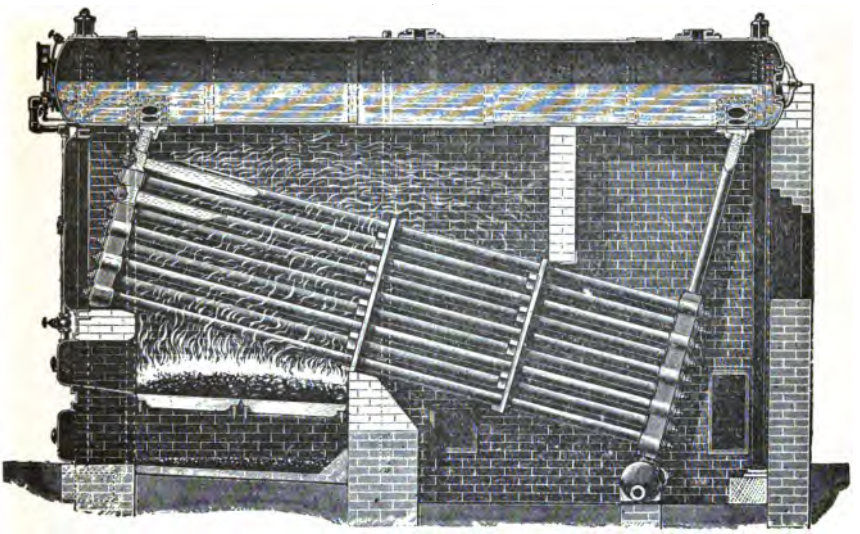


Fig. 11.

The mud-hole joints are faced to make a surface joint. The figure shews the direction of the passage of the furnace gases There are two partitions at right angles to the tubes so that the gases strikes the tubes three times on their way to the funnel. The water inside the tubes, as it is heated and evaporated, tends to rise towards the higher end of the tubes, and then into the main tube where the steam is given off to the steam pipe; the water then descends from the main tube through the tubes at the back, thus forming a continuous circulation. The mud-drum is provided with a mud-hole and blow-off cock. The greater part of the sediment will settle down in the mud-drum, from which it can be removed when required. The generating tubes are about four inches in diameter and seventeen feet long. The main separator is about

three feet in diameter, and over twenty feet long. In some cases the gases only circulate twice through the tubes. The feed water is pumped into the top main tube or separator and is arranged so as to give a direction of flow from front to back of the boiler. The internal feed pipe is extended beyond the inlet of steam and water from the generating tubes. In some of its detail this boiler resembles the Belleville boiler, but the author believes that it was in use for land purposes previously to the latter.

In the boiler shewn about one thousand square feet of heating surface, and twenty square feet of grate surface, are used. This should give about 500 indicated horse-power.

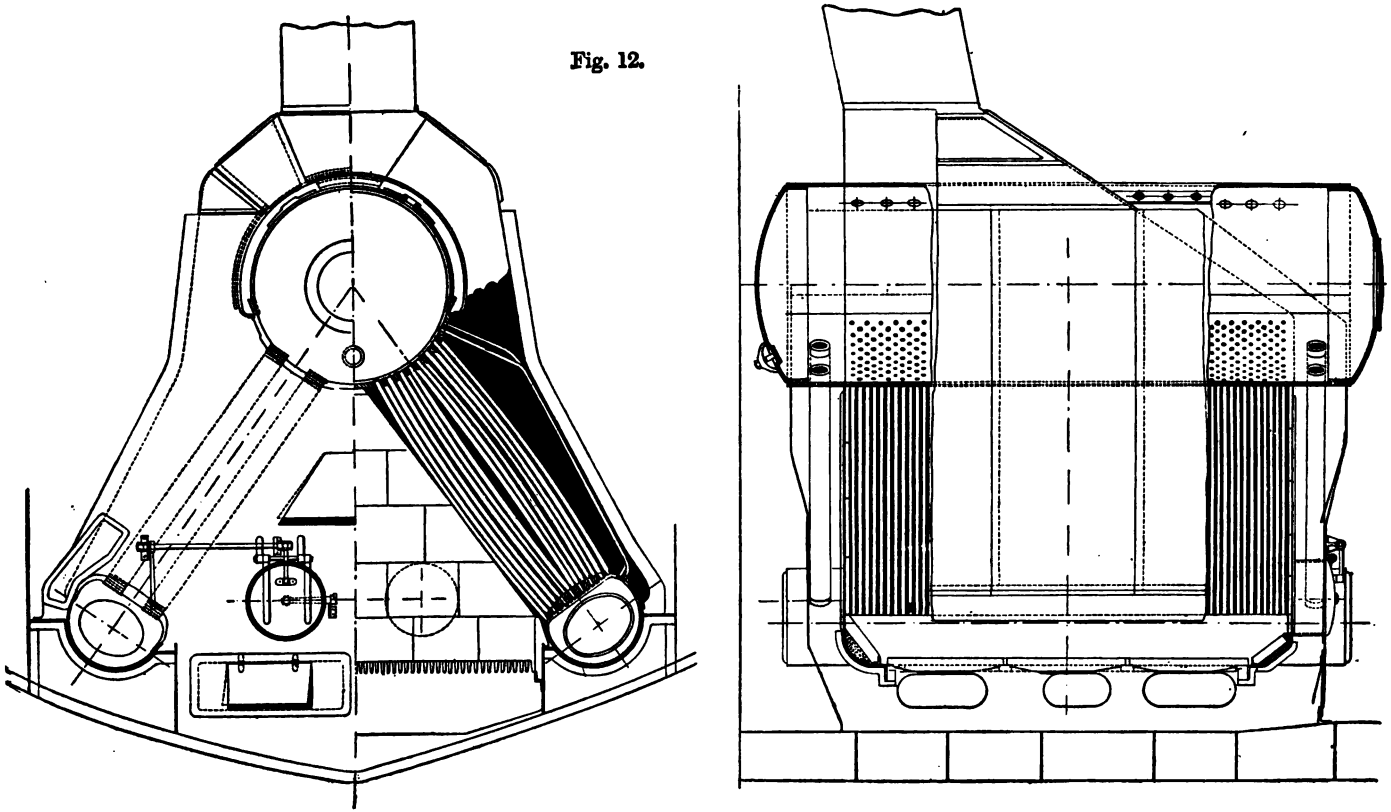
Exact particulars of the marine type are not yet obtainable, the boiler being still in a partial state of experiment, but for land purposes it has given great satisfaction for many years.

Blechynden Boiler.—This boiler is very similar to the Yarrow boiler. Front and side views in part section are shown in fig. 12. The generating tubes deliver their contents below water, that is, the top ends of the tubes are submerged. The generating tubes are not straight, but slightly curved, while the outer rows are made to shield the casing as in the Thornycroft boilers. A notable feature in this boiler is the plan, by which any single tube can be drawn out and replaced, without disturbing the neighbouring tubes. Sufficient height must be allowed for this purpose, or the deck above made portable.

Downtakers are fitted in a similar manner to the "Speedy" boiler, but there are eight of them instead of two.

Mr. J. Samuel **White**, of Cowes, has patented a boiler which is fitted in some Torpedo Boat Destroyers. This is shewn

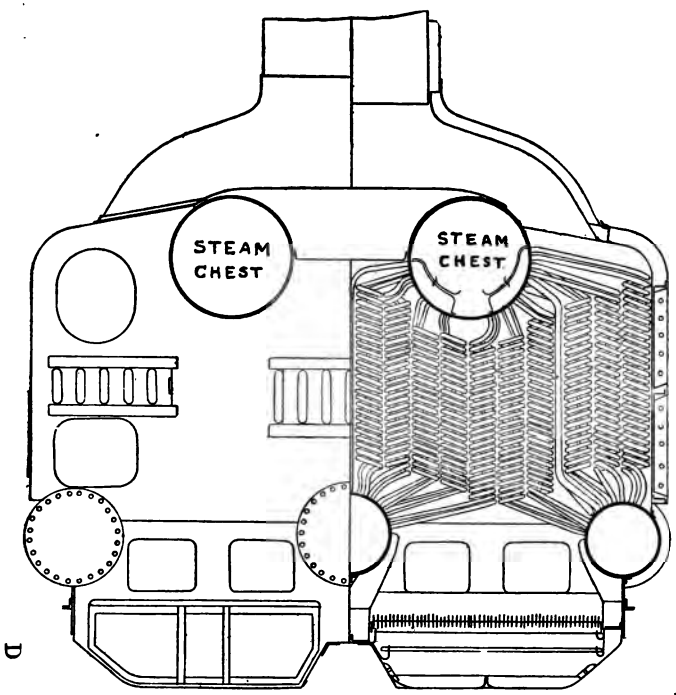
Fig. 12.



in fig. 13. The boiler consists of three lower water chambers, and two upper steam chests, connected by numerous water tubes, the whole being enclosed in a casing. The grate is below the level of the lower water chambers, a considerable space being allowed between the fire and the lower parts of the generating tubes, to serve as a combustion chamber. The front and back of the casing are shielded by generating tubes, which are reduced at the ends so as not to unduly weaken the chambers where they are jointed to them. Three longitudinal diaphragms, (one of which is immediately over the middle water chamber), of nearly vertical tubes, touching each other and with similarly reduced ends, extend from the front to nearly the back of the boiler, forming return flues. In this way there are four flues made. The products of combustion have thus to pass towards the back end, by the middle flues, and return, along the wing or outside flues, to the uptake and funnel. The flues are fitted with a number of spirals of small generating tubes, which are indicated in the figure. The diaphragms of tubes separating the flues are supplemented by baffle plates where necessary. The down tubes are outside the casing at the back end of the boiler. The provision for the circulation of the furnace gases by means of the return flues, is such as to insure their being brought intimately into contact with the generating surfaces, and to effectually prevent their taking a short cut to the funnel before parting with their heat. The middle water chamber is connected to both the steam chests, by the generating tubes, and is consequently somewhat larger than the two wing water chambers, into which fewer tubes are fitted.

Mr. White has been making boilers of a smaller type, with one steam chest and two water chambers, for some years for torpedo boats and launches with some success.

Belleville boiler.—This has been in use for many years and although no saving in weight is effected as compared with



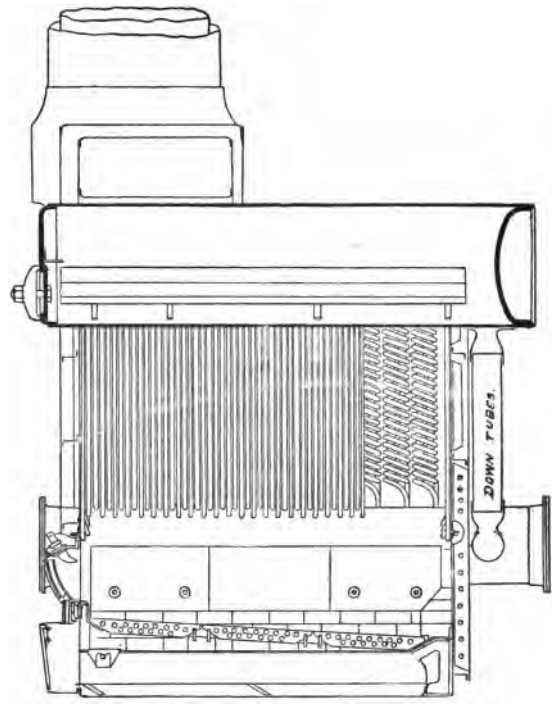


Fig. 13.

the flame tube boiler, the ease with which it can be worked, and the safety of working, has given it a prominent place as a good steam generator. It is built up of many tubes of about 3 inches in diameter, (see fig. 14.) disposed in groups which are gradually inclined upwards by raising opposite ends of the tubes, (which are straight) alternately. The junctions are formed at the end of each two tubes, one of which is inclined downwards to the junction box below, and the other inclined

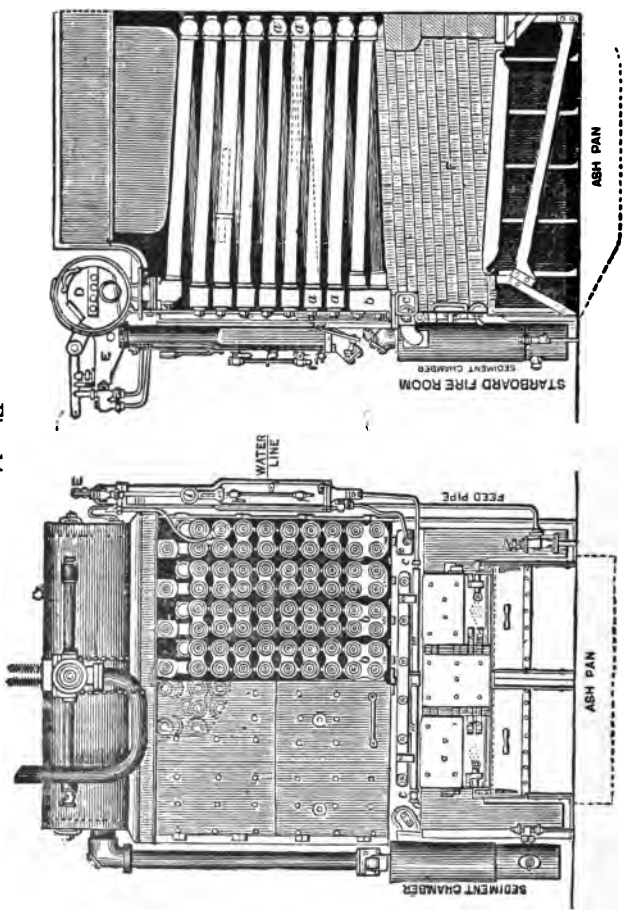


Fig. 14.

upwards to the junction box above. The lowest tube in each group is connected to the feed arrangement. The uppermost tube in each group is connected to the steam chest or separator. The feed water enters, for the generating tubes, from C into the bottom junction box *b*, and ascends by the tubes *a*, *a*, *a* until it enters the separator chamber D as steam and water mixed. The water falls to the bottom and is carried off into the sediment chamber, and is returned back through the generating tubes, supplemented by the feed water. The steam is carried off by the steam pipes through reducing valves, the usual practice with this type of boiler, being, to maintain a considerably higher pressure in the boiler than is required by the engines. By this means of wire-drawing, any water which may pass off with the steam is evaporated. The water line is kept a little above the middle (vertically) of the generating tubes, the feed being controlled automatically. The fires are forced by means of air jets delivering air, at a pressure of about 30 lbs., direct above and on the fire.

The **Yarrow** boiler, shewn in fig. 15, consists of one top main tube, or separator, and two bottom water chambers, the upper and lower tubes being connected by the generating tubes The separator tube is circular in section, the lower part forming the tube plate. The water chambers are nearly semi-circular in section, the upper parts being flat and forming the tube plates. The water chamber and tube plate are bolted together forming a joint of somewhat large dimensions. The generating tubes are straight, and in the "Hornet" were originally of copper. The copper tubes have however been removed and steel fitted. Some of the generating tubes also serve as stays between the tube plates. With the copper tubes it was easy to bend them slightly, and put them in place after the stay tubes were fitted. When fitting the steel tubes the boiler must be hoisted sufficiently to remove the lower part of the

water chambers to allow the tubes to be run up through the lower tube plate. The water chambers form the seat of the boiler, so that in this type much difficulty is experienced in renewing tubes. For plugging tubes any intervening tubes must be cut out, and the holes plugged, unless sufficient hoist can be obtained in the vessel to admit of the lower portion of the water chambers being removed. All the upper tube ends

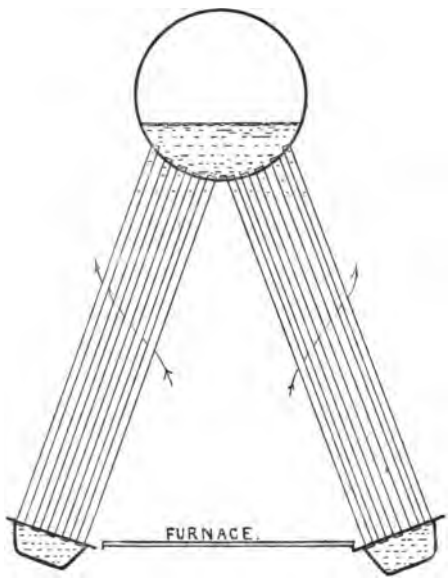


Fig. 15.

are accessible by means of a man-hole door, but here again great inconvenience is caused by many of the mountings being attached to the door. There are no *down-takers*, and consequently the circulation is of the alternating kind. The tubes deliver their contents below water, that is to say, when the water level is steady, the top ends of the tubes are submerged. One of the " Hornet's " boilers evaporated 12,500 lbs. of water per hour, from a temperature of 60° to steam at 200 lbs. pressure per square inch. The weight of the boiler (with

fittings, fire bars, funnel and in fact everything except the coal on the bars), is a trifle under 5½ tons.

Mr. Yarrow believes these boilers to be thoroughly satisfactory even when fitted with copper tubes, and so far results have justified his belief, as regards his own particular type. Personally the author does not advocate the use of copper for any part of a high pressure boiler, but he would like it to be noted that Mr. Yarrow's belief is based on great personal experience, and experiment, extending over many years, and his opinion should be received with due deference.

Reed's Boiler.—A front elevation in section, is shewn in fig. 15 A. This is very similar to the Normand Boiler, but the

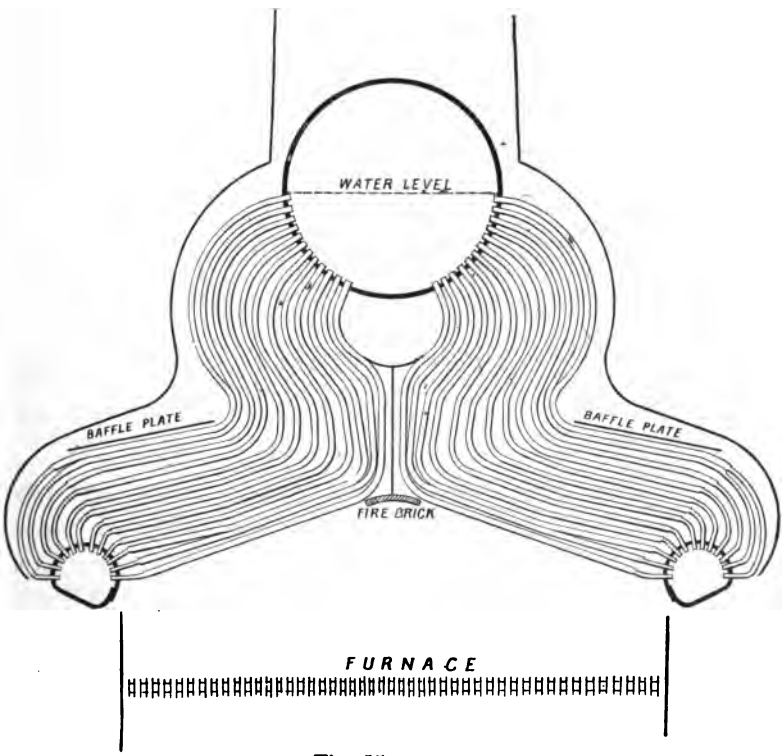


Fig. 15a.

generating tubes deliver their contents below or at the normal working water level.

There is one top main tube or separator, about three feet in diameter; and two lower main tubes or water chambers, each about eleven inches in diameter in the upper part, the lower part being flattened. On these flat surfaces hand holes are fitted for access to the lower tube ends, each tube is secured in the tube plate by a gun metal nut on the end of the tube, which is screw threaded, and is held in place by a gun metal cap, which makes a surface joint on the flame side of the tube plates. The lower ends of the tubes are drawn down to a smaller diameter where they fit into the tube plates. A casing surrounds the boiler and in certain parts baffle plates are fitted to prevent the flames taking a short cut to the funnel. The fire grate extends nearly the whole width, but only about two-thirds of the length of the boiler. The circulation is continuous, four down-takers, each, about seven inches in diameter being fitted, one externally to the casing at each end of each water chamber.

The feed water is delivered into the upper main tube, near the top ends of the *down takers*. The feed water is regulated automatically.

A steam dome is fitted above the main tube, and the steam is wire-drawn to produce a certain amount of superheating.

An area of about fifty square feet of heating surface is provided per square foot, of fire grate. About twenty horse power is indicated per square foot of grate, and this would give about $2\frac{1}{2}$ square feet of heating surface per indicated horse power.

Fleming and Ferguson boiler.—This boiler is made in various sizes to suit requirements, a description of one however shews the general dominant principal. There is one top main

separator or steam and water tube, about six feet in diameter and two water chambers, each about three feet in diameter. The main tubes extend the whole length of the boiler, and are connected by numerous curved generating tubes, each two and half inches in diameter and made of iron. The fire grate extends practically over the whole of the ground space below the water chambers, and the products of combustion rise up amongst the tubes on the way to the chimney. The chambers are built into the frame work of the boiler casing before the tubes are fitted, so that the tubes have no strain on them due to the weight of the boiler. The tubes are expanded in the usual manner, and beaded over for jointing into the tube plates. They are made with their upper ends one-sixteenth of an inch larger in diameter, and their length is such that they can all be put in place, or withdrawn, from inside the steam chest. Any one tube can be cut out and replaced without disturbing the neighbouring tubes. Although the tubes are curved, owing to their comparatively large diameter, a light held at one end may be seen to shine through the other end if they are clear. The number of lower water chambers is sometimes increased to three or four for larger boilers.

Performances of water tube Boilers.—These in some cases have been very remarkable, and wonderful results have been obtained. No actual comparison can be made between them individually but we must take them generally and then the results are somewhat as below.

The figures are the actual amount of horse-power indicated per ton weight of boiler, (including water in boiler to working height, funnels and all other fittings in the boiler-rooms belonging to the boiler).

Ordinary cylindrical, flame tube or tank boiler single ended (fig. 2) with 2 in. air pressure	30
Locomotive marine type (" Seagull " class)	32

Belleville, (water tube), (natural draught) - - 32

Thornycroft "Speedy" type, (forced draught) - 50

Average of "Daring" type, "Normand" and "Yarrow" (forced draught) - - - - - 100

Unfair comparison must not be made between water tube boilers of different types, each has its advantages. Although an enormous amount of water may be evaporated by one type, it does not follow that it leaves the boiler as pure steam. We do not know the amount of forcing which took place, and are ignorant of the amount of coal that was burnt to produce these results. The amount of air pressure used in the stoke-hold is of very little use as a guide to the amount of forcing, as the stoking alone may make the recorded pressure unreliable. It is correct however to state the amount of forcing used to obtain 32, with a locomotive boiler was as great, if not greater, than that required for those in which fifty was obtained. The water tube boiler has established itself as an economy in weight, and at lower powers (burning not more than thirty to forty lb. of coal per square foot of grate) it has proved itself an economical generator of steam. Further economy may still be gained by obtaining dry or pure steam from the boilers. This probably means an increase in the heating surface, and consequently the weight. If the increase is taken as a matter of course, and boldly, the economy of the production of steam will probably more than balance the increased weight. It has been stated that the water tube boiler is only suited to small fast vessels, this has not been proved in any way and it appears that if a boiler can stand the rough usage of a small vessel, with a not too reliable source of supply or reserve of fresh feed water, that it should be at least quite as suitable to a larger and better found vessel, where better and greater facilities are given for proper maintenance.

CHAPTER IV.

COMBUSTION.

UNDER ordinary circumstances, combustion means the chemical union of a combustible with oxygen at a sufficiently high temperature. Thus three things are necessary for the combustion of fuel, for in addition to the fuel itself, it must be supplied with a sufficient quantity of oxygen, and the temperature must not be below a certain limit. The oxygen is usually supplied by the surrounding atmosphere but in certain cases, artificial means are used to increase the supply. This process is adapted in most steamships, the air not coming down the hatchways or ventilation trunks rapidly enough, the fires burn languidly and therefore fan engines are used. Secondly a combustible is required. This is generally a Hydro-Carbon and composed of the following chemical substances:—

	Carbon.	Hydrogen.	Oxygen.	Sulphur & Ash.	
Welsh, Coal.	84	5	4	7	per cent.
North Country, Coal.	82	5	6	7	„
Patent fuel, (average.)	84	5	3	8	
Petroleum.	85	13	2	—	„

Of these substances, carbon and hydrogen are called the Combustibles, and by their union chemically at a high temperature with the oxygen of the atmosphere, combustion is effected. It is true that combustible substances will unite with oxygen at all temperatures; but that union is effected so slowly at low temperatures, and the heat developed so slight, that for all purposes for which the fuel is required, it is so small that it may be considered as practically non-existent. It must not, however, be entirely unnoticed for it is owing to this chemical

change that coals become deteriorated by exposure to the open air, and this change is facilitated by the action of the sun and rain, in the latter case the oxygen of the water supplying the place of that from the atmosphere. *Spontaneous combustion* is also owing to the same cause. Suppose a quantity of damp coal shut up so that any heat which may be generated, will not be able to escape readily. The water becomes decomposed into its two gases, oxygen and hydrogen, the oxygen unites with the carbon of the coal, and a slight development of heat is the result. The heat thus developed, fosters the same process between other particles of carbon and oxygen, and the combinations proceed with increasing rapidity, the temperature at the same time rapidly increasing till the coal becomes red-hot; and in addition, a considerable quantity of hydrogen, which was one of the ingredients of the water before its decomposition, is contained within the mass; this is another combustible substance, ready to burst into a blaze as soon as, in endeavouring to put out the fire, an opening is made for the atmospheric air.

It is only, however, at an elevated temperature that a common fire burns; and if from any cause the temperature of the surrounding substances be lowered, the fire will cease to burn briskly. For this reason, air is frequently heated before it is allowed to enter a furnace; and from inattention to this fires are often extinguished by putting on fresh coal when the fires are low. When coal is heated gases are given off, represented by the chemical symbols CH^4 and C^2H^4; these are known as Marsh gas and Olefiant or Heavy Carburetted hydrogen.

The heat given out by the combustion of hydro-carbon fuels is represented in thermal units as under.

Total heat of combustion of 1lb. of fuel.

$$=14{,}500 \left\{ C+4{\cdot}28 \left(H-\frac{O}{8} \right) \right\}$$

where C = fraction of carbon contained in the fuel.
H = „ „ hydrogen contained in the fuel.
O = „ „ oxygen contained in the fuel.

The number of pounds of air required to chemically burn one pound of fuel—

$$= 12C + 36\left(H - \frac{O}{8}\right)$$

In Chapter II. it was described how temperature was measured, and how heat could be transformed into mechanical work, and its equivalent and vice versa, and also that the relations of temperature and pressure had been determined experimentally.

From the table given at the end of Chapter I. it will be seen that the total heat required to evaporate one pound of water from 32° and at 212° (atmospheric pressure) is about 1146 Thermal units.

Therefore the number of lbs. of water that can theoretically be evaporated from 32 F. and at 212°

$$= \frac{14500}{1146}\left\{C + 4{\cdot}28\left(H - \frac{O}{8}\right)\right\}$$

$$= 12{\cdot}74\left\{C + 4{\cdot}28\left(H - \frac{O}{8}\right)\right\}$$

For purposes of comparing evaporative powers of different coals the *sensible* heat is generally omitted, and the equivalent *from, and at,* 212° *F.* substituted.

That is, theoretical evaporative power—

$$= \frac{14500}{966}\left\{C + 4{\cdot}28\left(H - \frac{O}{8}\right)\right\}$$

$$= 15\left\{C + 4{\cdot}28\left(H - \frac{O}{8}\right)\right\}$$

Applying this to the proportions for average Welsh coal

$$= 15\left\{84 + 4{\cdot}28\left(5 - \tfrac{1}{2}\right)\right\} \div 100$$

$$= \frac{15}{100}\ (84 + 4{\cdot}28 \times 4{\cdot}5)$$

$$= 15\tfrac{1}{2} \text{ lbs. about.}$$

In practice this is seldom or never obtained, a fair average result is only about 9 lbs. and in some extreme cases as much as 10 lbs. of water evaporated per one lb. of coal.

The reason of this is that, some of the gases escape unburnt or only partially burnt, the carbon having an insufficient supply of air for combustion, goes up the chimmey as carbon mon-oxide instead of carbonic acid or carbon di-oxide The heat of combustion of carbon mon-oxide is only 4,400 thermal units and that of carbonic acid 14,500 thermal units. Again if the supply of air is excessive, (through holes in the fire or other means), the total temperature of the excess air has to be considerably raised and this causes a loss. There is also a loss from unburnt coal falling into the ash-pit with the ashes; waste by external radiation and conduction; and, waste in the funnel itself as all the heat is not abstracted before its escape to the outer atmosphere.

Both oxides of carbon are invisible and it is therefore very difficult when steaming to know whether the coal is being properly burnt or only partially. The supply of air should generally be greater rather than smaller than that actually required chemically, and in designing appliances and areas for the supply of air double the quantity is generally allowed for ordinary chimney draught, and about one and a half times the quantity for artificial draught.

The loss from unburnt coal can only be prevented by careful stoking and reburning all ashes after sifting them. With good stoking this should not amount to more than three per cent, of the total loss.

The loss from radiation should not be very great if the boiler is properly lagged and the furnace doors kept closed. This is a loss whose proportion depends in a great measure on the design of the boiler and casing. It is very small in some water-tube boilers in which the outer tubes form the wall of the furnaces and combustion chambers.

The loss up the funnel is very considerable and must remain so where quick rates of combustion are expected. Rankine found that the funnel draught occasioned by the heated gases is a maximum when:—

$$\frac{T_2+461}{T_1+461} = \frac{25}{12} \text{ where,}$$

T_1 = Temperature of external air.

T_2 = „ „ gases in base of funnel.

461° is the absolute zero of the air thermometer.

For the ordinary temperature this gives about 600°F. as the temperature which gives the most efficient draught. The temperature of the fire in a furnace is about 2,400° above the external air, and as the temperature in the chimney is only required to be 600° to produce the maximum draught, it is only necessary to expend about one-fourth of the heat in creating chimney draught. With modern high pressures where the temperature of the steam in the boiler is about 400° F., it is difficult to keep down to this limit, and 750° is a common temperature at the base of the funnel. With forced draught it frequently rises to about 1200°. This accounts for a great deal of the loss which obtains at high rates of combustion, and for economy, the boiler power should be considerably increased and by this means a less degree of forcing be required.

Rate of Combustion:—In the Merchant Service when working economically with funnel draught only, the coal burned per square foot of grate per hour varies from 15lbs. to about 20lbs., according to the length of the grate. The short grate is much more efficient; and economy, in some cases where the width or diameter has been very small, has been gained by actually reducing the grate surface. Mr. Seaton states that "the efficiency of a grate over four feet in length varies nearly inversely as its width." In practice a good stoker can stoke a grate up to six feet long, but not more, in a fairly efficient manner, and in designing a boiler this should be

taken into account. Mr. McFarlane Gray's rule that "the consumption of coal per square foot of grate is very nearly proportional to the diameter of the furnace," is found to be fairly correct in practice. In water-tube boilers, however, where there is plenty of height above the fire this would hardly hold good, and by inclining the grate in these boilers so that the lower end is towards the door, it is probable that the consumption would vary directly as the area of the grate, up to a reasonable length of grate, say six feet six inches. After this it is probably a matter of conjecture and no rule can be stated, as it entirely depends on the personal factor of individual capabilities in stoking. The rate of combustion is enormously increased by artificial draught, and varies from 25 to 96 lbs. per square foot of grate, when the draught is from half an inch to six inches of water pressure by the air gauge. In torpedo boats the higher rates are generally obtained and in one torpedo boat destroyer nearly 100 lbs. was burnt with an artificial draught of about two inches, although these boats are fitted with grates up to seven feet in length.

The principal plans for obtaining artifical draught are :—

1.—Induced, or drawing the products of combustion up the funnel by means of a fan or blast.

2.—Closed stokeholds, the stokeholds being filled with compressed air by means of fans.

3.—Closed ash pits, the furnaces and ash pits being supplied with compressed air, the stokeholds being open.

4.—Jets of liquid fuel, blown over the incandescent coal as used in the Italian Navy.

None of the first three methods seem to have any great advantage over any other, and for this reason they are all adopted, and used as convenience or first cost may sanction.

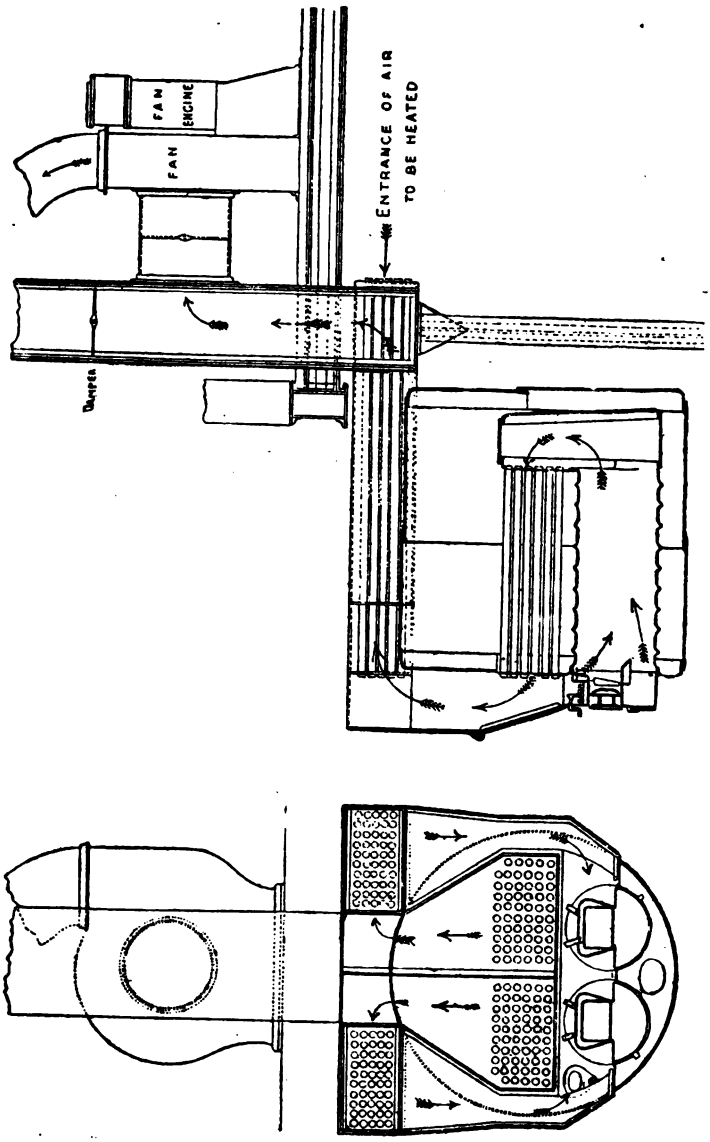


Fig. 16.

Induced draught appears to have one great advantage not as a better means of obtaining high rates of combustion but as a convenience, the stokeholds are always open and are cool and clean and comfortable, the stokeholds being much better ventilated by this means. Also the boilers are easier to superintend when under steam than when the stokehold is closed. It is claimed that under this system better rates of combustion are obtained and if we may take the locomotive boiler of an express train as an example, good results are obtained by using the exhaust steam for inducing funnel draught. The Ellis and Eve's system shewn in figure 16 has met with some success, and Martin's system tried in H.M.S. "Gossamer" was eventually successful, but neither of these methods shew any particular advantage over the closed stokehold system in increasing the rate of combustion. The air is heated by tubes inside the uptakes in the Ellis and Eve's system, and as high pressures become more generally adopted and consequently greater temperatures of the steam, this will become an important item in the wear and tear of the boiler. Probably some such system will be adopted for supplying heated air to the furnaces.

Where saving of weight is concerned the closed stokehold system gives best results. The size of fan is only one half that necessary to give the same draught as with induced draught. The *steam blast* is a ready method of inducing a draught, but at its best it is a very wasteful method both as regards fuel and water, and is not now used in ships. A jet of compressed air has been giving some satisfactory results, the jet being taken into the base of the funnel induces a draught, the pressure being from 30 to 40 lbs. in the pump. For small increases this is an economical and useful method of increasing the rate of combustion, but it entails an engine and blower of possibly greater weight than that used for forcing by other means.

Blowing jets of air into closed ash pits has been in use for some years, this was introduced by Mr. Howden and is used in many Atlantic steamers. The air is heated before being blown into the furnaces and ash pits. The possibility of a back draught is always present but with ordinary precautions should not take place, as the air jet is shut off from each furnace by the action of opening the furnace door.

The closed stokehold system is that generally adopted in the Navy and where not carried to excess is a very useful expedient. The weight required is not great, but it involves closing the whole of the stokehold into an air tight space, in which the men on watch are shut in. For this reason it has some objectionable features, the chief being the difficulty of outside superintendence of the boilers when steaming. It is however comfortable, cool and safe when the stokehold is closed, and in case of accident if the fans can be kept going, no back draught should occur. Whenever such accidents have occurred it has been generally found that some exit for the air other than the furnaces and ash pits has been open. A complete system of double doors has to be fitted for entry and exit to the stokehold. The bunkers being shut off from each other, the particular bunker required to be worked can be kept open. The fan engines are sometimes in the stokehold and sometimes, as in large ships, fitted on a deck above the stokehold. In any case it is advisable that they should be controlled by some means of opening or closing the steam valve to the fan engines, from both inside and outside the stokehold.

The Belleville boiler is forced to a slight extent by means of a jet of air blown into the furnaces, the pressure in the jet being about 30 lbs. per square inch. This method has been adopted in many other systems in a modified way, no doubt a jet sets free many of the gases in the coal played on, and thus promotes an increase in the rate of combustion.

The *Liquid fuel* method hardly comes under the head of artificially produced combustion, as it is obtained principally by the combustion of the liquid itself. It is, however a cheap and ready expedient for producing high powers, and many spaces now unoccupied in ships might be utilized as storage tanks for this combustible. Its Calorific value is about 20,000 thermal units, and little of this is lost, so that probably in practice double the weight of water could be evaporated by one lb. of petroleum than is evaporated by one lb. of good Welsh coal. Its weight is somewhat less than coal but being liquid the stowage is required to be only about two-thirds that of coal. Its advantages are thus very great as compared with coal, and if the price can be kept also within certain limits it is very inexpensive in comparison with coal. The difficulty of obtaining further supplies of liquid fuel must however militate against its use in men-of-war. A ship would be able to steam at least twice the distance using liquid fuel than it could steam with good coal, the weight of fuel carried in each case being the same.

CHAPTER V.

FITTINGS AND MOUNTINGS OF BOILERS.

Safety Valves.—Figure 17 shews a sectional elevation of one of a pair of valves such as is generally fitted for marine boilers. It is fitted into the valve box which is bolted on to the boiler direct, at or near the highest part of the steam space. The valve is generally loaded by springs of spiral form and square section, as shewn in the figure. The spring is compressed the

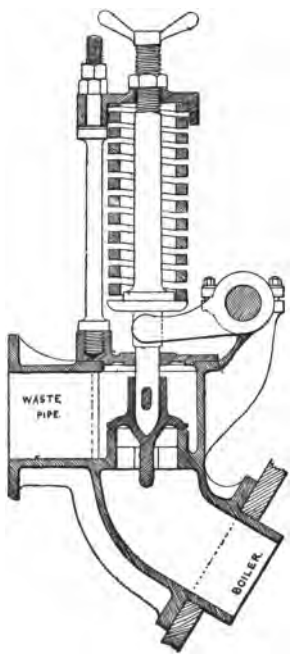


Fig. 17.

required amount, so that the valve will just lift against the pressure exerted by the spring, when it is exceeded by the

pressure inside the boiler. The valve is free to move to a slight extent on the spindle so that if the spindle is not quite in line, the valve will keep on its face.

The valves are generally made with flat seatings and not coned, and this makes them less liable to stick fast in the seating. A T handle is provided at the outer end of the spindle, so that the valve can be moved round on its face when steam is up. For working or lifting and trying the valves, a system of levers is provided and by their means the valves can be lifted against the pressure of the springs from the stokehold platform, and also generally from the deck above. The lift of the valves should be about one quarter the diameter of the valves. The area through the safety valve openings is laid down in the Board of Trade rules on this subject, and varies according to the working pressure, and other conditions of working for which the boiler is intended. A drain pipe is usually fitted so as to keep the valve box clear of water above the valves, if a cock is fitted in this pipe it should always be kept open. At least two valves should be fitted to every boiler, and frequently with large boilers three or four are fitted. The safety valve box should be entirely separate from the steam valves and internal steam pipe. The gross area of safety valves is about two-fifths of a square inch, per square foot of grate surface.

Hydrometer or Salinometer.—This instrument is used for measuring the quantity of salt or other solid matter in the water, inside the boiler, evaporator or elsewhere.

Sea water contains one thirty-second part of solid matter by weight, and if a certain portion of the water be evaporated it is evident that the proportion of solid matter must increase. Thus when the water contains double that contained in ordinary sea water, the proportion of solid matter will be 2/32 and so on. The amount of this is measured by the

hydrometer, which consists of a float, below which a weight is suspended, and a graduated stem rising above the float. Sometimes this is graduated shewing $\frac{1}{32}$, $\frac{2}{32}$ and so on, but in the Navy it has been divided into parts called degrees, ten degrees corresponding to each $\frac{1}{32}$ part of solid matter. Thus the density of fresh water will be zero, of ordinary salt water 10, and of water which contains 4/32nds of solid matter it will be 40. The density of the water depends also on the temperature of the water, and consequently the graduations are made to suit the temperature for which it is required. The usual Naval hydrometer is graduated for two temperatures that for 100° Fahr., being placed on one side of the stem, and that for 200° Fahr., marked on the reverse side. The two sides are shewn in the figure 18, and it will be noticed that the hotter water shews nearly 10 degrees more density than the cooler water. The density of the water also affects the boiling point which is about 1·2° higher for every $\frac{1}{32}$nd part of solid matter. Thus the boiling point of ordinary sea water at atmospheric pressure is 213·2° Fahr., instead of 212° which is the boiling point of fresh water.

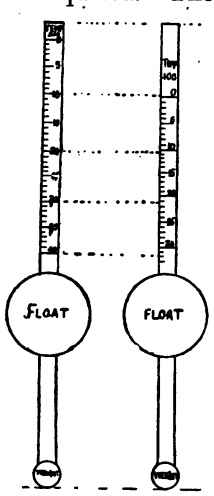


Fig. 18.

Loss from blowing down.—The weight of water which is admitted to the boiler as feed, is not all evaporated, when the boiler requires blowing down to reduce the saltness of the water.

If the brine blown out be supposed to contain n times the density of the feed water.

and x = weight of steam used,

y = weight of water blown out.

Then, if the feed water contains $\frac{1}{a}$ part of salt.

$$\text{The weight of salt pumped in} = \frac{x+y}{a}$$

$$\text{and, The weight of salt blown out} = \frac{n.\ y}{a}$$

If we keep a constant density the weight of salt blown out must be equal to the weight of salt pumped in.

$$\text{Therefore,} \quad \frac{x+y}{a} = \frac{n.\ y}{a}$$

$$\text{and,} \quad y = \frac{x}{n-1}$$

From which we find that the weight of feed water required is equal to $x.\frac{n}{n-1}$

and the weight of water which must be blown out is

$$= \frac{x}{n-1} = \text{loss from blowing out}$$

$$\text{or proportionally} \quad \frac{y}{x} = \frac{1}{n}$$

For example if $n = 1$, Then, $y = x$

$n = 2$, Then, $y = \frac{1}{2}x$

$n = 3$, Then, $y = \frac{1}{3}x$

$n = 4$, Then, $y = \frac{1}{4}x$ and

if $n = 2$. quantity of feed required $= 2x$

$n = 3$, quantity of feed required $= \frac{3}{2}x$

$n = 4$, quantity of feed required $= \frac{4}{3}x$

$n = 5$, quantity of feed required $= \frac{5}{4}x$

and so on.

The loss of heat may be calculated as below.

Let x = quantity of water evaporated.

y = quantity of water blown out.

t = temperature of feed water.

T = temperature of evaporation.

Then, the brine being blown out as water at temperature T, the loss of heat = y (T−t).

The heat expended usefully, that is in evaporating the water

$$x = x\left\{ 966+0{\cdot}3(T-t) \right\}$$

Expressed as a fraction the loss is

$$= \frac{y\ (T-t)}{x\left\{ 966+0{\cdot}3(T-t) \right\}}$$

If the density be kept at n times that of the feed water

$$\frac{y}{x} = \frac{1}{n}$$

Therefore the loss will be $= \dfrac{(T-t)}{n\left\{ 966+0{\cdot}3\ (T-t) \right\}}$

Example (1). If, n = 4 times density of sea water, and the feed water be of the same density as sea water as in a jet condensing engine. Let t = 60

T = 300

Then loss $= \dfrac{300-60}{4(966+72)} = 0{\cdot}057$

Example (2). If the density be kept at 40 by the hydrometer, and the feed water has a density of two degrees.

Then, n = 20. Let t = 100

and T = 300

Then loss $= \dfrac{300-100}{20(966+60)} = 0{\cdot}0097$

From this it will be seen that although the amount of water blown out is very great in proportion to the amount of feed, yet that the loss of heat is comparatively small. The application of these calculations is very useful in working evaporators.

Stop-Valve.—The steam in the boiler communicates with the steam pipe leading to the engines by means of a stop-valve. These valves are generally made self closing, that is, the pressure inside the boiler being suddenly released, (from a tube bursting or any other cause) the valve will close of itself, so that steam from other boilers should not be wasted

through the valve into the boiler, and so into the stokehold. Figure 19 shews one usually fitted, it will be seen that the spindle is connected to the valve itself and is provided with a T handle so that it can be turned round on its seat. The amount of opening is regulated by the wheel which is attached

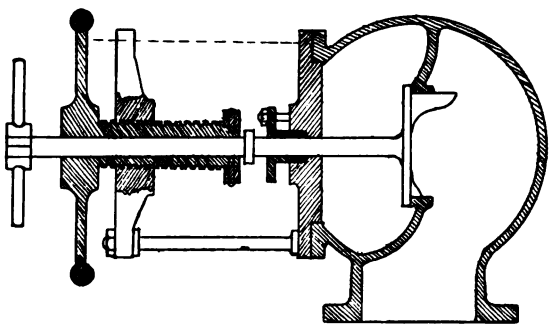


Fig. 19.

to a hollow screwed spindle. When the valve is required to be opened the wheel is moved with a left-hand motion, and when the screw is thus drawn back sufficiently the T handle is worked or pulled back. These valves have saved many accidents from being of a very serious nature, and if kept in good order are almost certain of action.

Care should also be taken that the valves are properly open by personal inspection of the wheel and spindle. The area through the valve is generally about one-fourth greater than the area of the steam pipe connected to it. The stop-valve casing has a spigot cast on it, so that this spigot projects inside the boiler. To this spigot the *internal steam pipe* is connected. The latter is generally of brass and consists of a pipe running horizontally along the top of the steam space, with slits cut on the top side, the slits are generally made about one-third the circumference in length. The object of this pipe is the prevention of water being carried off with the steam into the pipes, and so to the engines. It has been found a good preventitive of *priming* when the priming is not

excessive. Whenever the boiler is opened for examination or cleaning, these slits should be carefully inspected to see that they are not choked, and if necessary the pipe taken down and thoroughly cleaned.

An auxiliary stop-valve is fitted also to connect up the boiler to the auxiliary steam service, this has its own internal pipe also, and is made self-closing in the same manner as the main stop-valve.

Feed Valves.—Usually two are fitted to each boiler, one from the main engines (or Main Feed pump) and the other from the Auxiliary or Donkey Feed pump. When looking towards the boiler the Main Feed should be to the right, and the Donkey feed to the left hand. These valves are screw-down non-return, that is, they will lift when the pressure in the pipe exceeds that in the boiler but in no other way. By screwing down the spindle (fig. 20) the valve can be closed off, or the amount of opening regulated. The valve casing should be cast with spigots, so that the internal pipe may be connected This pipe should be led in such a way, that the feed water should have the same direction as a descending current, which should surround it, so that no steam would get into the pipes. A precaution is generally taken against this happening by drilling a few small holes at any possible pockets on top of the pipe, near bends, etc. The faces of the valves should be flat and not angled especially for high pressures, this reduces the hammering of the valve considerably, and there is less chance of the valve becoming fixed in the seating. The feed valve should be capable of being regulated from the stokehold platform, and should be regulated with the pump, to give a constant supply in proportion to the work the boiler is doing. If they can be controlled automatically

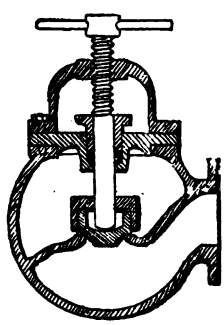


Fig. 20.

so much the better, and in boilers in which the amount of water contained is very small, and the generating power very great, some automatic arrangement is generally fitted as in the Thornycroft and Belleville type. In these boilers in which the total water contained in the boiler at working height, requires to be entirely renewed about every ten minutes, when working at full power, it is evident that personal attention must be erratic, and wherever mechanical means can be used instead of manual, the work is performed much more efficiently.

These arrangements for automatic feeding should be examined at every convenient opportunity, and should not interfere with the usual methods of feeding the boiler if they get out of order. So successful has this automatic feeding become in the Belleville type, that these boilers are frequently fitted without gauge glasses to show the water level.

Thornycroft automatic Feed Arrangement.—In figure 21 a part section of the upper or separator chamber is shewn with an arrangement for feeding automatically or more correctly for maintaining a constant level of the water in a group of boilers. A small wheel A which can be worked from the stokehold platform, works a screw spindle in a bracket outside the boilers. The spindle passes through the end of the separator and is jointed at B to a long rod B C. This rod operates on a bell crank CDE pivoted at D. By working the

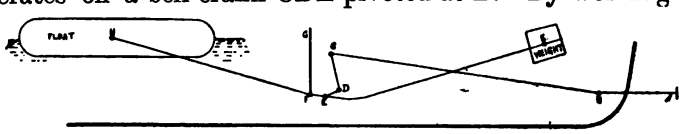


Fig 21.

wheel it will be seen that the point E may be raised or lowered as required. A weight K and a float H are balanced on the point E by means of a bent lever. To this lever the spindle FG of the internal feed valve is attached. As the water is lowered in the boiler the float lowers and, bringing

down the point F with it, opens the valve. When the water is too high the float rises and closes the valve. If a higher level of water be required to be maintained then the bell crank is brought into operation by raising the point E.

The valve is of the balanced or double beat kind (similar to that shewn in figure 58), and no glands are fitted to the valve box, thus giving a perfectly free movement with very small friction.

The usual fittings for feeding are fixed outside the boiler so that if necessary the feed can be shut off entirely. A pressure is maintained in the feed pipes of about fifty pounds above that in the boiler, and under these conditions good results are obtained.

Pressure Gauges.—This instrument is used to measure the pressure of steam in the boiler. The front is graduated to a certain scale, and the dial with a pointer indicates the pressure at all times, (see figure 22.) It is connected by means of a small copper pipe, (from $\frac{3}{8}$ to $\frac{1}{2}$ internal diameter) to the



Fig. 22.

steam chest of the boiler, generally at the top, and the gauge itself being placed so as to be easily visible from the stokehold platform.



Fig. 23.

The mechanism, (see figure 23,) consists of a bent tube, communicating with the steam pressure, and a quadrant, with a pinion or small cogged wheel attached to the spindle of the pointer. The action is obtained by fixing one end of the tube, and leaving the other free to move and actuate the quadrant by its movement. The bent tube, under pressure greater than that of the atmosphere, will tend to straighten itself owing to the greater length of the outside diameter or bend of the pipe and therefore there is a greater *total* pressure outwards. If the pressure is less than that of the atmosphere, the pressure of the atmosphere will tend to bend the tube in still further, so that the gauge can register pressures both above and below that of the atmospheric.

A stop pin is fitted to prevent the pointer going completely round the gauge. If the casing is made water tight these gauges are very reliable, but when subject to moisture they

should be carefully examined occasionally by taking off the back cover to see that the mechanism is free, and experience will show those gauges most likely to need examination.

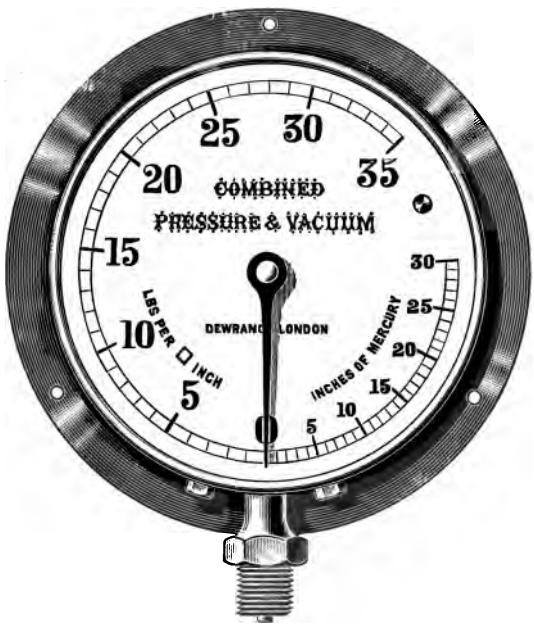


Fig. 24.

Figure 24 shows a *compound* or combined gauge which is graduated for both pressure and vacuum, or actually pressures above and below the atmospheric pressure. These gauges are generally fitted to the engine receiver pipes, backs of slide valves, to the condenser and to evaporators.

The vacuum gauge shewn in figure 25, is used for the condenser. The vacuum is generally expressed in inches of mercury, 30 inches being equal to 14·7 lbs. below the atmospheric pressure. This is the zero of *absolute* pressure. The mechanism is similar for pressure, compound and vacuum gauges.



Fig. 25.

Water gauges.—The level of the water in the boiler is shewn outside the boiler by means of a glass tube fitted between two cocks one communicating with the steam space, and the lower one communicating with the water space of the boiler In some cases these are fitted to a *steady pipe*, which itself forms the connection with the steam and water spaces, but the direct fitting is far preferable, there being, less chance of choking up and shewing false water. Care should be taken not to place the connections with the boiler, near to any opening where a current of steam or water is passing, since the level of the water may be effected thereby, a difference of pressure of one tenth of a pound causing an alteration in level of $2\frac{3}{4}$ inches.

All boilers should have two sets of gauge fittings, and it is usual to fit double ended boilers with three.

By means of the drain cock the glass can be kept fairly clean, but care should be taken not to open or close any of the cocks suddenly. Thus by closing the lower cock, (the top one

being open), and opening the drain cock, steam will blow through the glass and clear it, this also will shew that the top cock is clear. Then by opening the lower cock and closing the top one, it can be ascertained that the lower cock is clear. In its normal working state the handles of the cocks should all hang downwards.

The usual type of water gauge fitted to high pressure boilers is shewn in figure 26. The handles are adapted to be

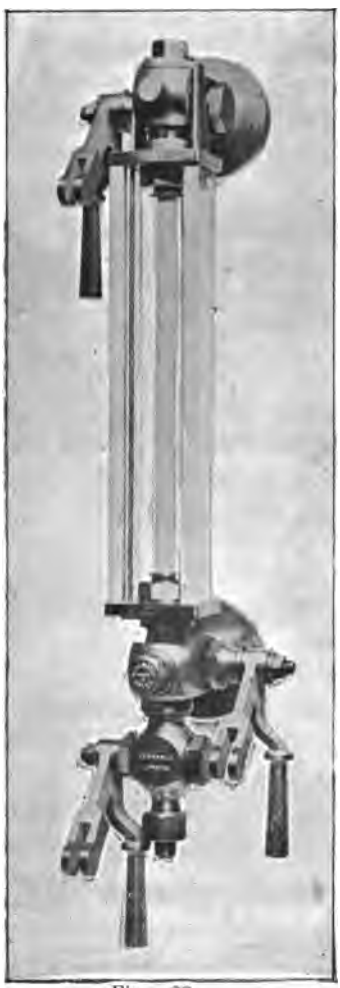


Fig. 26.

worked by iron rods or wire, the latter being preferable as each cock can be worked independently, or in the event of the glass breaking they can be closed together by one string. Water gauge glasses are liable to break at any moment, and an automatic valve has been devised by Messrs. Dewrance, that will shut off the rush of water when the glass breaks. This arrangement is shewn in figure 28. By shutting off the two

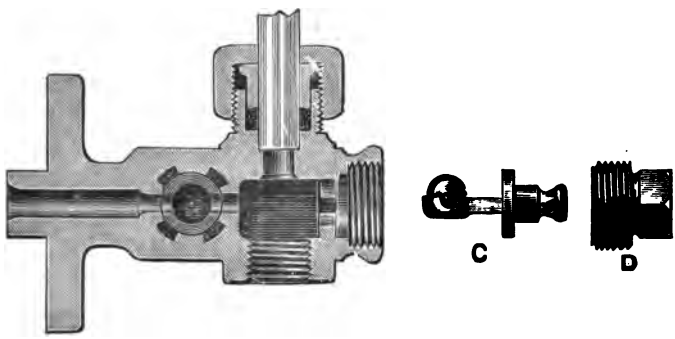


Fig. 28.

arm cocks, and opening the blow through or drain cock, the automatic valve can be examined *when steam* is up. Then unscrewing the cap in front of the lower arm, and taking out the support the ball valve can be cleaned and examined.

The action is simple, under ordinary conditions the valve remains on its support, but a sudden escape of pressure caused by the breaking of the glass, lifts the ball and closes the aperture at the end of the glass. They are usually only fitted to the water or lower end of the gauge glass, and in practice this arrangement works well, and is a great convenience. It is preferable to have the gauge fitted direct on to the boiler, and not with a steady pipe, but in this case the cocks should be fitted with flanges and not screwed into the boiler. This preserves the perfect alignment of the glass tube and glands. In fitting a new glass it is well to make sure that the glass has been annealed; this can be done by boiling them, warming the glass and water together and letting them cool gradually. For

high pressures over 200 lbs. say, the glass should be blown at the ends, and not cut or ground, so that the surface presented to the steam is a polished or glazed one, and not rough or splintered. Leaving the glass cut or rough reduces the strength and durability considerably, this reduction is estimated at from 40 to 60°/₀.

In some instances with high pressures *talc* has been substituted for glass. The arrangement (see figure 27) of cocks etc., is exactly the same, but in place of the glass tube a brass pipe is substituted, with two flat sides, to which the talc is secured by brass plates with long slots. The *talc* is flat and very thin, but some difficulty is experienced in seeing the water level unless the light is very good. In all cases the lamp should be placed *immediately behind* the gauge and not in front.

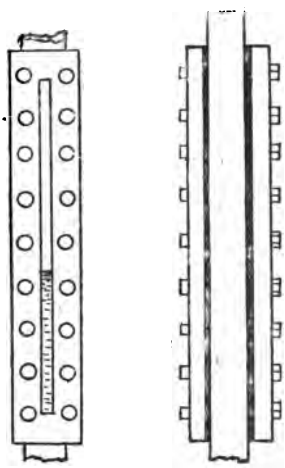
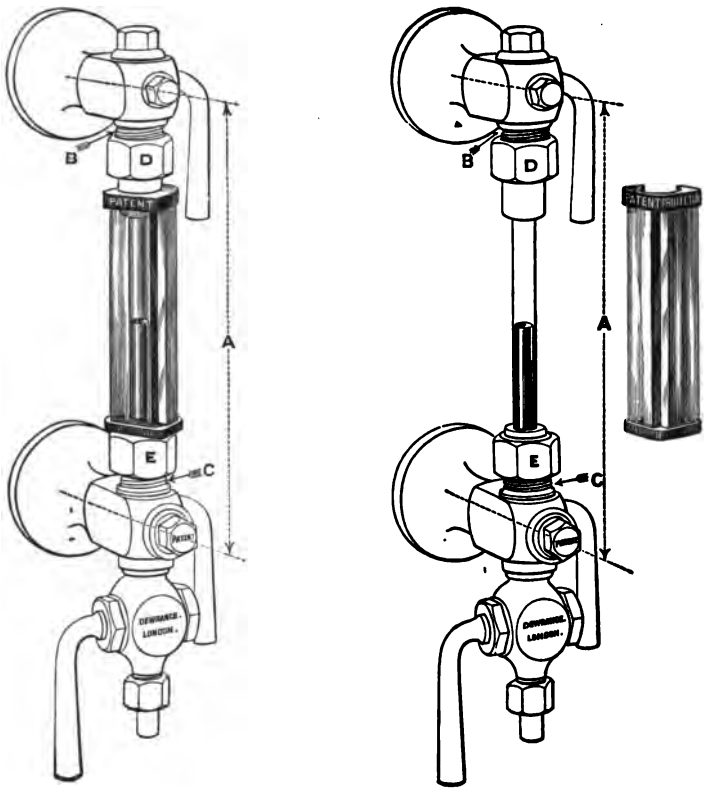


Fig. 27.

Glass protector for water gauges.—These are a safe guard against fragments or splinters from a burst glass. The protector shewn in figure 29, does not obstruct the view of the water level, and can be put on and taken off easily. It is supported by the two nuts D and E. Protectors are only fitted to boiler gauge glasses, or other parts where the glass tubes are subject to great pressure. At parts other than the above and where the tube may be easily broken from some external cause, a brass guard is sometimes fitted. A brass guard is unsuitable for any part so important as a boiler gauge.



Figs. 29.

Blow out Cocks.—These are not now fitted to blow out overboard when surface condensing engines, and means of making up loss of fresh water, are used.

A valve however still known as the blow out is fitted on the lower part of the boiler, for emptying the boiler by either running the water into the *double bottoms* or the bilge. (The double bottoms referred to apply only to those used as reserve feed water tanks.) In some cases the valve is fitted about two feet from the bottom of the boiler, so that only clean water is run off. This is convenient in ships where the boilers are greasy or limed with scale. By using a hose

the boilers can be levelled through the blow out valves. A *surface* blow out or *brine* valve is usually fitted to all boilers so that the surface of the water can be cleared of grease from time to time.

Asbestos packed cocks are used for nearly all connections which are subject to boiler steam pressure. Figure 30 shews a sectional elevation and plan of a Dewrance balanced plug cock with spring holding down plate.

The plug does not touch the metal surface, but works entirely on a non-metallic bearing of specially prepared asbestos packing, caulked into the grooves in the shell and vulcanized. This packing is shewn in black and around the way by dotted lines. The plug is balanced by drilling a small hole shewn. The plug is kept in place by a holding down plate, and is prevented from being blown out by the square cover. The gland is used for keeping the space around the spindle, steam-tight only.

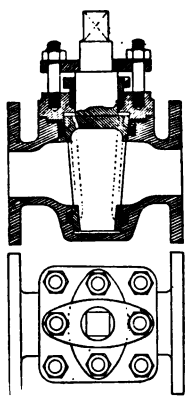


Fig. 30.

Asbestos packed cocks are used for many duties, principally for parts connected with steam pressure. Gauge, drain, blow out, brine and boiler test cocks are the most frequent. For the larger sizes the fitting, usually takes the form shewn in figure 30. For test cocks a common type

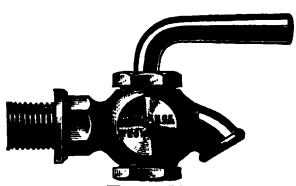


Fig. 31.

fitted is shewn in figure 31. Other types are shewn in the sketches of water gauge fittings.

Hydrokineter.— Where feed heaters are not fitted for flame tube boilers, there is generally a great range of temperature of the water in the boiler itself, and it is a common experience to find the bottom of a boiler, especially when of the double ended common combustion chamber type, quite cold after it has been in use for several hours. This inequality of temperature brings on many strains from unequal expansion of the various parts of the boiler and generally the tubes next the combustion chamber become leaky, and subsequently also the joints of the furnace and the lower part of the shell. The cause of all these troubles is one thing only, where the workmanship is above suspicion, and can be traced to a bad circulation of water in the boiler. Many attempts have been made to promote circulation, when the original design of the boiler has been defective, and in some cases the defects have been overcome by artificial means. Such means are shewn in figure 32, which gives a section of Weirs

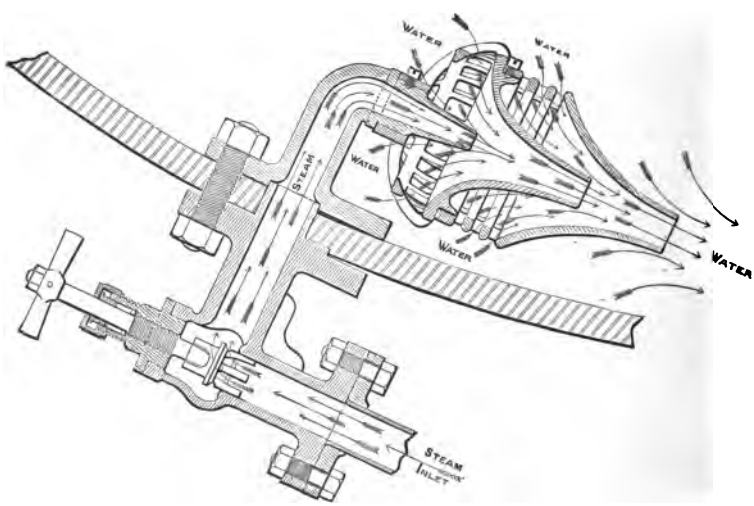


Fig 32

hydrokineter or water circulator. The three-nozzle type is shewn. The flange of the first, or steam nozzle, is fixed on the inside of the boiler shell near the bottom of the boiler, and the nozzle set in the direction the circulating current is to take. On this nozzle are fixed two outer or induction nozzles, and the back end of the one, and the outer ring of the other, are perforated to admit water between them. Steam from another boiler is admitted by the check and stop valve to the steam nozzle, and getting condensed, throws a jet of water through the second nozzle. The volume of water is increased in passing through the outer nozzle. It then enters the bottom of the boiler and induces a current. The purpose the two outer nozzles serve, is, more effectually to direct the force of the jet in the direction circulation is desired. When a steam jet enters openly, as the water gets heated to a certain temperature, the steam, on leaving the nozzles, expands and impairs the force of the jet.

In this arrangement the water being directed on the steam jet, the steam is condensed between the first and second nozzles, until the temperatures of the water reach about 270° Fahr. The outer nozzles then come into play as a condenser, keeping the steam from expanding, and directing the jet straight into the water in the bottom of the boiler, until the pressure reaches that of the steam jet. The check valve now closes to prevent the water being forced back into the other boiler.

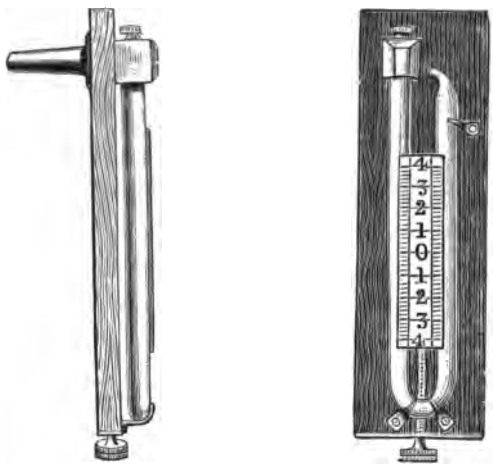
It is a most useful instrument for raising steam quickly in large flame tube boilers, and it should decrease the wear and tear of the boiler very considerably.

With a well designed boiler there should be no necessity for an instrument of this kind, after steam has been raised, but owing to the difficulty of finding boilers so well designed, where weight and space have been much curtailed, some such arrangement is a great assistance for many services. Galloway

tubes are perhaps the best form of promoting circulation, but the system of a separate combustion chamber for each furnace is that now generally adapted.

Means of circulating in a natural and continuous manner are provided in most water-tube boilers.

Air pressure gauge.—This is shewn in figure 33, and is actually a form of water barometer. It consists of a bent



Figs. 33.

tube of U shape, one end of which is connected by tubing to the outer air, and the other end is open to the stokehold or connected by tubing to the place required. Water is put in up to any level required, and when both ends are open to the atmosphere, the height of water in the two parts of the tube will be the same. But when from any cause there is a preponderance of pressure as in a closed stokehold, the water level connected to that side will be pressed down and the other will rise up. The difference of level measured by a scale attached is the pressure in inches (scale) of water. If on the other hand one end be connected to the funnel and the other to the atmosphere, the pressure in the funnel being less than that on the outside will draw the water up on that side instead

of pressing it down. There is then a vacuum of so much measured by the scale. The height of the water barometer is about 33 feet, and that of the mercury barometer is about 30 inches. Consequently a mercury barometer is unsuitable for extremely small differences, and the water barometer is preferred, giving an accuracy at least twelve times as great. Half an inch of air pressure by the water gauge would only shew about one twenty-fifth of an inch on the mercury barometer, which is hardly perceptible.

Ash Shoot.—One of these is generally fitted to each boiler room, it is generally a circular tube leading from the level of the upper deck to within four feet of the stokehold platform.

If fitted in this way they may generally be used as Ventilators, but with forced draught appliances they cannot generally be used in this way. A small double cylinder engine, capable of being reversed, is generally fitted for hoisting the ashes at each shoot.

Armour gratings.—In ships fitted with armoured or protective decks, the hatchways and the funnel interior are fitted with armour grating, to protect the uptakes and boilers from shot and shell. The arrangement is shewn in fig. 34. The gratings are usually movable and hinged so that access can be obtained from below to the upper part of the interior of the

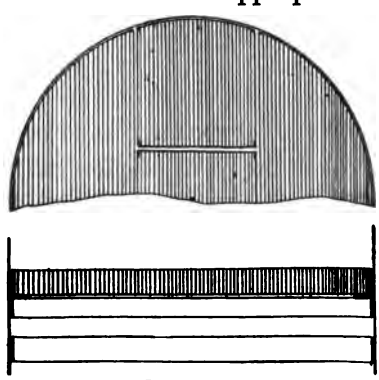


Fig. 34.

funnel, or hatchway. They are fitted in a similar way in the ventilating shafts, and in the hatchways to allow for removing large pieces of machinery from below.

Superheaters.—Are not now fitted, as it is thought that the higher pressures now used do not require them. They are undoubtedly economical, but the economy does not always compensate for the additional weight and trouble involved by their use. At present with the slight liquefaction due to the radiation from the steam pipes, etc., it is found that oil for internal lubrication of the engines can be entirely dispensed with, the water of liquefaction serving as a lubricant. Very dry steam has the effect of scoring the sides and working surfaces of the cylinders and slide valves. This roughness brings on a lot of extra work so that although theoretically we should obtain more work from the steam, in practice this possible gain is counterbalanced by not superheating and obtaining smoother working. The economy of superheating must not be discarded, there is much room for improvement in the economy of the engine, and superheating plays an active part in furnishing this economy.

Very few boilers generate pure steam and the quality of the steam should be the standard from which superheating should be viewed as an economy or otherwise. An increase of thirty per cent., in the power given out by an engine with superheated steam is not uncommon.

The economy of superheating is very closely allied to that of steam jacketing. It is possible that in the near future efforts will be made in the direction of obtaining a better quality of steam (that is, with less moisture in suspension). This better quality may be obtained either by additional heating surface in the boiler itself or by superheating. The steam jacket may be dispensed with and a *closed* air casing substituted.

Funnel and Uptake.—The smoke and hot gases after leaving the smoke boxes, are conveyed from the different boilers, through passages, called the uptakes, to the funnel. The area of the funnel is usually from one-seventh to one-tenth the area of the fire grate. The plates separating the several uptakes are carried a sufficient height up the funnel, to cause the smoke and gases to move in approximately the same direction, when they mingle together, so as to avoid loss of draught from shock or confusion of currents.

The funnel is surrounded at its lower part by an outer casing forming an annular air space. The heat radiated from the funnel is thus intercepted, and the ascending current of air, is carried up into the atmosphere, a sufficient height above the upper deck to prevent inconvenience to the people on board. This casing is also used as the outlet for ventilating the bunkers and some other parts of the ship.

Telescopic funnels.—Are sometimes fitted to ships with sail power, the funnel being hoisted or lowered as required, by means of chains and pulleys fitted on the lower part, the power being obtained by worm and pinion gearing.

Funnel Stays.—Are fitted to the upper part of the funnel to steady the funnel when the ship is rolling or pitching. These stays are fitted with screws or other means of adjustment to regulate the strains, and should be slackened before raising steam to allow for the expansion of the funnel as it becomes heated.

Funnel covers.—Are fitted on top of the funnel for use in harbour, when the fires are not alight, to prevent rain coming down the interior and corroding the uptakes and other parts. The covers are kept a little above the top so as to allow sufficient space for the escape of the smoke from the small fires used for airing and preserving the boilers.

CHAPTER VI.

CARE AND MAINTENANCE OF BOILERS.

Care and maintenance of boilers.—An accumulation of ashes is a thing to be guarded against, and they should be drawn out whenever possible. In water tube boilers they accumulate among the tubes, and cannot, unless, special doors are fitted be cleared when underweigh, so that whenever the engines are eased or stopped the spaces between the tubes should be swept and cleared as far as possible, and as opportunity offers the surfaces should be cleaned. Soot is a very bad conductor of heat and consequently any small scale on the heating surface would considerably reduce the evaporative power. The water should be as pure as possible and with the evaporators now generally found in ships, this is not a very difficult matter. Salt and impure waters are a frequent cause of *priming*. The use of either can be guarded against except in extreme cases and even then if they are admitted in minute quantities, as make-up, the danger of priming is reduced, but it cannot in some boilers be entirely overcome. Priming generally occurs from irregular working more than from the nature of the feed water. In boilers with a sediment box, this box should be blown out frequently and in other boilers a judicious use of the brine valve reduces the chances of priming and scale forming considerably. The Belleville boiler is fitted with a sediment chamber and in the Thornycroft the sediment appears to accumulate in the lower water chambers, and when the boilers are opened this can be washed out. These boilers hold a very small quantity of water at working height, and consequently the loss when emptied for cleaning can be easily made up by the evaporator.

Economy of fuel can be obtained by careful stoking and the coal should be handled with a shovel, care being taken to have the coal small enough to part with its gases easily, and at the same time not small enough to fall through into the ash pit.

The coals should be thrown on evenly and the average thickness of the fire should be not greater than six inches. The fire bars should be cleared from below by means of a pricker and not poked from above, (this entails opening the doors to the furnaces and admitting cold air).

The ashes should be sifted or riddled, and the small coals thrown back on to the fire. With a fire of five inches in thickness, the supply of air should be sufficient to check smoking, and at the same time give sufficient air for combustion of the gases. Holes in the fire should be guarded against, as a large volume of cold air may be admitted in that way. If the gas goes up the funnel as carbonic oxide, only 4,400 thermal limits of heat are given out, but if it can be properly burnt by a sufficient supply of oxygen 14,500 thermal units can be given out of 1lb. of coal. Therefore, within ordinary limits, it is better to have too much rather than too little air supplied. Because the coal has disappeared from the grate, it does not necessarily follow that it has been usefully burnt, and thick fires, through which a sufficient supply of air cannot penetrate to the part above the fire or the combustion chamber, should be carefully avoided.

Under forced draught a *thin* fire is quite as nccessary for good combustion. The air pressure in a *plenum* (or closed stoke-hold) can be considerably reduced by efficient stoking, and for this reason the amount of air pressure is a very unreliable guide unless the fires are well stoked and are kept a proper thickness. Good stoking alone will increase the indicated horse power or evaporation of a boiler by at least 10 per cent., and instances have come under the author's notice where the increase has been over 25°/₀.

The steam pressure should be kept constant and the feed water should be supplied continuously and, if possible, automatically controlled. The furnace doors should be kept closed, and opened for as short a time as possible when firing up.

The ash pit water service.—Should be used as little as possible, and at moderate speeds not at all. Vaporisation takes place, and particles of water are taken bodily into the fire and generally deposited round the combustion chamber, leaving a scale of lime and soot. When ferrules are fitted, or with tubes of small diameter, this leads to nesting at the combustion chamber ends of the tubes. This nesting is most objectionable and the tubes under forced or induced draught are almost closed in, after 8 to 10 hours working, and either fires have to be drawn to clear them, or such of them as can be got at from the stokehold cleared by means of a T bar or some such contrivance. It is evident therefore that although a temporary gain may be made by the use of water in the ash pits, that it is temporary only. With corrugated furnaces frequently a splash plate is fitted to the bottom of the ash pit, to facilitate drawing ashes. The water from the ash pit water service is evaporated and leaves a cake of salt and ashes which is most difficult to remove, and the wear and tear from continual cleaning is very considerable.

It appears a better practice to dispense with both ash pit water service and the ash plate. The wear and tear in this way is considerably reduced, and a larger area is obtained below the fires for the admission of air. With the Morison furnace which appears to have an advantage in this respect an ash plate is entirely unnecessary. With water-tube boilers the ash pan is a necessity, but the water service may be dispensed with when steaming at ordinary powers, if proper care is taken to draw the ashes and keep the pans clear. The scale, formed unnecessarily by the injudicious use of water,

decreases the efficiency of the heating surface, and at the same time makes it very difficult to remove. It is claimed for the system of ash pit water service, that it prevents the bars being burnt, this may be so, but proper stoking will produce the same effect with no decrease of efficiency.

With water-tube boilers the fire grate should be inclined upwards as it leaves the furnace doors, or at any rate it should be made horizontal, this gives the stoker a much better opportunity of stoking evenly, and so prevents *holing*, a common occurrence when the grate is inclined downwards at the back as in flame-tube boilers. This inclination was originally given to make a greater opening into the combustion chamber, and at the same time make a greater opening for admitting air to the ash pits, without decreasing the effective area of the grate, which could be applied in any given diameter of furnace.

When banking fires they should be banked in front if banked at all, generally this is unnecessary; the fires should be allo wed to burn down as low as possible and a little fire kept alight at the front end and thus prepared for pushing back. If the fires are dirty, the clinker should be broken by using the pricker under the grate, and when the fires are sufficiently low, taken out, the fire then being banked up at the front end ready for pushing back as necessary. Care should be taken to keep the fire well back from the dead plate at the furnace door. When cleaning the fire the ash pit damper should be kept closed, in short, the furnace door and ash pit damper should never be open at the same time. If these details are intelligently carried out, freedom from leaking at the joints of the furnaces and tube ends should be obtained.

When lighting fires in a boiler with more than one furnace, it is customary to light up one fire first to promote circulation. In a flame-tube boiler, due regard should be paid to the position of the furnaces. Generally the direction of

circulation should be upwards in the middle, and the down currents following the shape of the shell towards the bottom. Thus in a three furnace boiler the centre furnace should be lighted up first, and the wing furnaces later and together. When common combustion chambers are fitted, or two or more doors to one furnace, as in the Thornycroft and other boilers one door should only be opened at a time, the furnaces should be fired alternately so that the green coal only partially covers the grate, and the gases will then enter the combustion chamber at a sufficient temperature to thoroughly burn them. A routine of firing should be laid down suitable to each boiler, and always carried out, and a similar routine laid down for cleaning fires and sweeping tubes when under way. All parts of the heating surface should be kept as clean as possible and special attention should be paid to the furnace crowns and combustion chamber.

The interior of the boiler must always be kept clean and free from scale, and for this reason it is usual to examine each boiler at least once a month. In the Navy reasons have to be stated if this is not done.

Generally it can be done with little or no inconvenience, and, a good system is, that in this duty, each officer should take a section of the boilers and superintend their cleanliness. Every stoker should have his special boiler, and in this way very great efficiency may be maintained. The fact, that, when his particular boiler is clean it exempts him, except in case of emergency, from further very trying and dirty work, gives each individual a personal interest in his work which must give better results. The heating surfaces including the tubes are always the most important, but frequently corrosion takes place in the steam spaces and especially near the steam and safety valve orifices, and at the water line.

If the boilers are greasy which is frequently the case when kept quite fresh, a slight addition of sea water to the feed will generally produce a powdery scale which can be

easily brushed off. The density of the water in the boiler should not be allowed to exceed that of sea water when used for this purpose and generally about one half this density will do all that is required. The slight density will also prevent corrosion which is prevalent when pure fresh water is alone used. Due attention to the use of oil for internal lubrication is a very important factor in keeping boilers clean, and generally no oil should be allowed to be used in any auxiliary engines, and as little as possible in the main engines. Auxiliary engines are seldom steam jacketed, and the water of liquefaction should always be sufficient internal lubricant. Care should be taken that the zinc slabs are in good order, and properly connected electrically to the boiler. The orifices in the internal steam pipes and all other connections should be inspected and if necessary, cleared. Any internal apparatus, such as automatic feed, or hydrokineter, should be examined and if necessary refitted.

The Safety valves, and all other valves and cock connections, require frequent examinations, and the springs need testing from time to time in accordance with instructions laid down on this subject.

A chipping *hammer* should not be used for cleaning the interiors, but the scale should be scraped or brushed off. When there is any roughness from chipping, it is always difficult to remove the scale subsequently.

In water tube boilers no scale should be allowed to collect or form, and it will be found that washing out immediately after opening the boiler, will generally leave the boiler quite clean, as far as can be seen, but to prevent accidents it is advisable to pass a wire or marble through each tube occasionally to ascertain that all tubes are clear.

If a tube cannot be cleared, the ends should be plugged and a small hole drilled in the tube, to prevent any accumulation of pressure bursting the tube.

At the first opportunity the tube should be cut out and a new one substituted. The preservation of the tubes on the flame side, is an important and a somewhat difficult matter on which to form a good practice, and the examination of some parts is almost an impossibility. Generally the rule is to keep the boiler dry by maintaining a higher temperature than the surrounding air, experience can only shew how efficiently this method has been carried out. That it is efficient, there is no doubt if properly and intelligently used, but under certain circumstances when ships are laying up, it is difficult, as there must be certain intervals when no fires can be lighted.

If not required for some time the boiler may be kept empty and open so that there is a free circulation of air through the boiler, but the most efficient method for preserving the interior, and also a most convenient one is by means of charcoal. The boiler is thoroughly dried, and if necessary a wood fire lighted for this purpose in a furnace, and then the boiler closed up while warm. Just previously to closing up, glowing charcoal in pans is introduced into the boiler and the charcoal absorbs the whole of the oxygen in the boiler.

Animal or vegetable charcoal is generally preferable as it is free from sulphur and other deleterious elements. The boiler is then kept hermetically closed until required. This is a good method when the boiler is not required probably for some months, but when there is no chance of freezing the water the boiler is pumped up quite full, a slight pressure being obtained to expel all the air.

After boilers have been steaming, if they are shut off before all the steam has condensed, they may be kept so for some time without injury, but if boilers are filled to working height or not quite full, steam should always be raised to expel the air, There is an important difference, whether the air has or has not been expelled before closing up a boiler partially filled with water.

The results of the effect of an accumulation of scale in boilers considered briefly are :—

1. Decreased efficiency of the heating surface, causing an unnecessary expenditure of fuel.

2. Increased temperature of the materials forming the heating surfaces, causing collapse or deformation of furnaces and leakage of tubes and joints.

3. Increased wear and tear of boilers.

4. Excessive boiler cleaning expenses.

Some very interesting investigations on boiler deposits have been made by the consulting Engineer to the Eastern Telegraph Company. He has given the subject careful study, on account of the nature of the work of cable laying, necessitating boilers being kept under steam for long periods. In one ship, after 110 days steaming, the boilers on being opened out, were found perfectly clean, and only required the light powder, with which the surfaces were covered, brushing down and washing out. In another ship after 103 days steaming, a similar result was obtained. An evaporator and a filter were fitted in each ship. These are good results and there is no reason that they should not always be obtained with intelligent working.

An analysis of the scale taken from some furnaces which had bulged and come down, the thickness of the scale not being excessive, is given below.

Gritty matter and sand	2.69	per cent.
Oxide of Copper	1.07	„
„ „ Zinc	3.42	„
„ „ Iron	24.21	„
„ „ Magnesium	16.52	„
„ „ Calcium	2.02	„
Oily matter of acid character, combined with oxides of Copper, Zinc, Iron and Magnesium.	32.02	„

The remainder being made up of oil in its natural state, but mechanically mixed through the deposit; and 0.07 per cent. unaccounted for.

This deposit therefore contains 50°/₀ of oil.

The oil on being examined was found to have a vaporizing point of 305 degrees Fahr., and was therefore altogether unsuitable for the internal lubrication of the engines.

The mineral oil supplied in the Navy for internal lubrication has a much higher vaporizing point, from 500° to 600°. But the best of oils vaporize to a certain extent or are carried off mechanically into the boiler, so that it is evident that some means should be adopted for preventing its entry into the boilers, and therefore whenever a filter is fitted it should always be used, and where it is not fitted the feed and reserve tanks should be cleaned frequently. The hot well should also be cleaned as far as possible, and the boilers brined to take the scum off the surface of the water. In some ships the feed tank is also fitted with a means of scumming and this should be used occasionally.

CHAPTER VII.

THE ENGINE.

The last few years have been prolific in the new and improved methods introduced into marine engineering; first the general introduction of surface condensation; then compound engines, triple expansion and quadruple engines, and the consequent changes in the boiler to produce the higher pressures of steam required for the various types. With all this however we are only working up to the forecasts of James Watt, who promised so much when steam could be used expansively, Although the engineering profession has been and is always ready to try new and approved theoretical principles, it has generally been the same story from the beginning, that the machine shops could not produce the material. There has always been delay in obtaining better class material for higher pressures, and new methods, although tolerably well known as practicable and economical, have been delayed for years for suitable materials to continue an otherwise interrupted progress. The machine shops must however have a demand for material before there can be a market. Much that we have learnt has come from private individuals or firms who have spent much trouble and money in experiments, and frequently the general body of engineers have required educating up to the standard of the new introduction. All this shews that the engineer must not only understand the way to hold a file or a hammer, but must also possess knowledge and experience to guide him into new paths. He must be able to foresee all results, and weigh and balance the advantages and disadvantages in his mind of both the possible theoretical economy and the possible attainment

of that economy practically. The best workman in the shop is not always the best engine driver, only experience can teach this, but if it is backed up by a complete and thorough knowledge of the mechanism, the time required for gaining the experience is comparatively small.

Thus for many years the compound engine was not adopted generally, until many minds had received sufficient knowledge to accept the innovation. The advantages are now generally allowed and it is almost unnecessary to touch on them. The same remarks apply to all compound engines whether, two-stage, three-stage, or any number of stages that may be used. The same general principles dominate them all.

The practicability of a high rate of expansion which is a first economy in steam engines was a difficult problem. The efficiency of any heat engine (of which the steam engine may be considered one) by Rankine's formula is $= \frac{T_1 - T_2}{T^1 + 461}$ where

T_1 = Temperature before work is commenced.

T_2 = „ when work ceases to be done.

and 461 is the difference between the ordinary zero and the *absolute* zero of the air thermometer, by the Fahrenheit scale.

Considering this equation, the greatest possible efficiency when T_1 is constant is obtained by reducing T_2. In the steam engine this was attempted by the introduction of the condenser. Thus instead of exhausting into the atmosphere at a temperature of about 212°, this was reduced to about 60° by exhausting into the condenser. As an example, let the initial temperature be 297° (corresponding to 50 lbs., pressure), then the efficiency, exhausting to atmosphere

$$= \frac{297 - 212}{297 + 461} = \frac{85}{758} = \text{about } 0{\cdot}112$$

and exhausting to the condenser, the efficiency is

$$= \frac{297 - 60}{297 + 461} = \frac{237}{758} = \text{about } 0.313$$

That is, a gain of nearly three times the efficiency by using the condenser. The gain varies for each pressure adopted.

The temperature of the exhaust steam in practice is about 90° in the condenser, corresponding to about 0·7lb., absolute pressure, and is frequently higher. Take 90°; then, considering the efficiency, when T_2 is constant, it is evident that to increase it, we must increase the initial T_1. The high pressures now used, correspond to a temperature of about 392°. Therefore the efficiency

$$= \frac{392 - 90}{392 + 461} = \frac{302}{853} = 0.355 \text{ about.}$$

But if the initial pressure be 50lbs., ($T_1 = 297$), the efficiency

$$= \frac{297 - 90}{297 + 461} = \frac{207}{758} = 0.273 \text{ about.}$$

This shews a gain by using the higher pressure of thirty per cent. Practically, by disposing the parts of the mechanism in a more efficient manner and by utilizing certain properties of steam when worked expansively the gain has been over 100 per cent.

With this large range of temperature from 392° down to 60° or 90°, expansion became almost impossible in a single cylinder. The first step was to jacket the cylinder, that is keep it warm by means of an outer casing into which the steam was admitted. This answered its purpose up to a certain point, when it was found that the amount of steam used in this way was resulting in a loss. Therefore to reduce the range of temperature which is obtained in every stroke of the engine the two-stage or ordinary compound engine was introduced: the cylinders still being jacketed.

As higher pressures have been introduced it has been found advisable to adopt a greater number of stages for expansion as in triple and quadruple expansion engines.

From time to time various methods have been introduced for transferring the work done on the piston to the shaft. The first and most general was, by means of a beam, connected to the piston rod end and to a crank by another connecting rod, the beam being pivoted at a point between the two

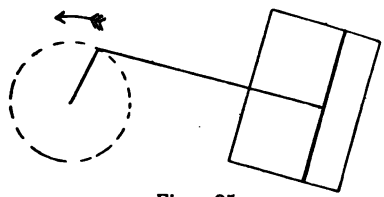


Fig. 35

connections. This gave way to the oscillating engine shown in diagram 35, the cylinder oscillating on trunions and the piston rod transmitting the work direct to the crank. This type is still used for some paddle engines.

When the screw propeller was introduced, an attempt was made to keep the machinery, (which was generally very heavy, as low as possible, and in the navy below the water line.

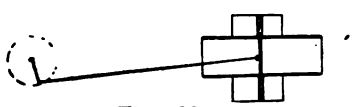


Fig. 36.

The space was somewhat confined and to obtain smaller ground space trunk engines, shewn in diagram 36, and return connecting rod engines shewn in diagram 37, were introduced.

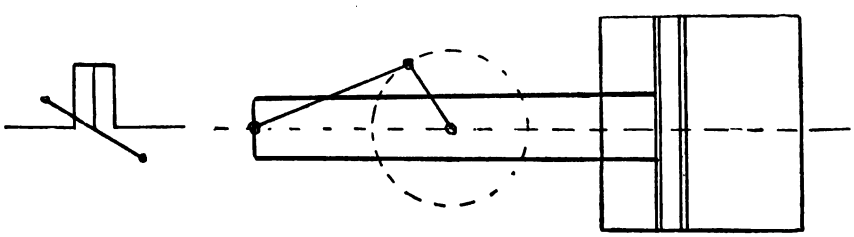


Fig. 37.

All these in turn have given way to the direct acting engine, diagram 38 which is usually of the vertical type with the cylinder at the top. This is the type of engine now generally adopted for all propelling and many general purposes.

By using a short stroke and adopting a short connecting rod, and increasing the piston speed by increasing the number of revolutions, it has been found possible to get the height of this type within such limits as to compare favourably for

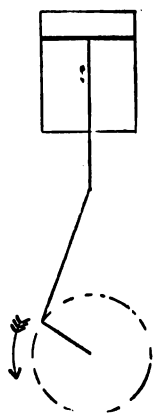


Fig. 38.

working with horizontal engines, although the latter may be of longer stroke. The ground space covered by vertical engines is much smaller, a great consideration, and although a certain amount of extra height is necessary it is not found excessive.

The number of cylinders has been gradually increased, and the tendency is still in this direction. Very large cylinders require much staying, and the piston rod must also be proportionately large, to withstand the possible bending strains which are put on it: although a smaller rod is quite *strong* enough, it is found that it is not always *stiff* enough for its work. If therefore a larger rod be used for the low pressure

or large cylinder, a similar one must be made for the other cylinders, or, it becomes necessary to carry spare rods of each size. The increase in the number of cylinders does not necessarily increase the number of cranks on the shafting, as arrangements can be made by which four pistons can operate on two cranks in which case an actual reduction takes place in the number of cranks compared with the usual three cylinder engine. The flywheel has entirely disappeared in well designed engines. At its best the flywheel could never be regarded as anything better than a very rough and ready method of balancing an engine.

Balancing engines has now reached a point where practical tests alone give the requisite information for producing motion without vibration. The Engine should be balanced as far as possible when designing it, and then if further balancing is required it should be suspended or supported on springs. Steam is then put on and if the engine is perfectly balanced the engine should remain perfectly steady when running. No load is applied in this experiment.

In fig. 39, a diagram is given of a simple engine with two cylinders, the cranks being generally made at right angles as shewn in the right hand figure. The arrow heads denote the course of the steam from the boilers. It will be seen that in

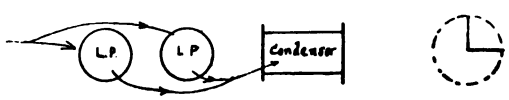
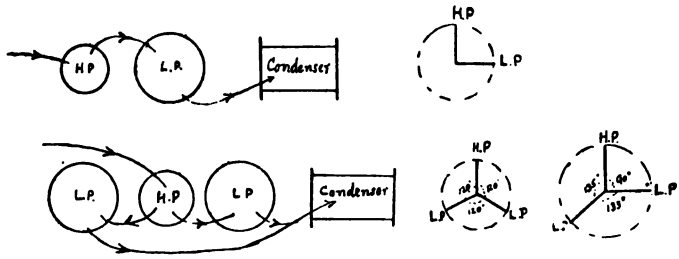


Fig. 39.

the simple engine, the steam goes to each cylinder direct from the boilers and the exhaust of each goes direct to the condenser.

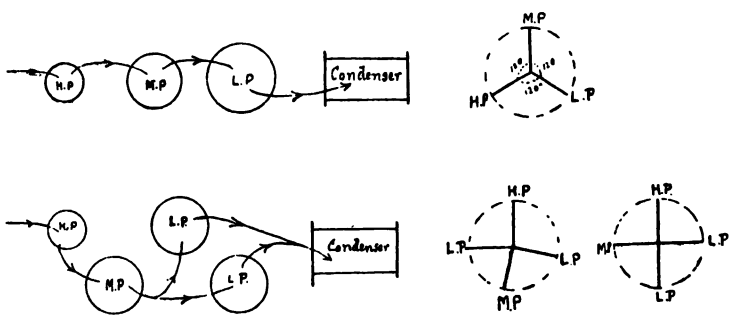
Fig. 40, shews diagrams of two cylinder and three cylinder two-stage or ordinary compound engines. Different makers have various ways of disposing the cranks, but there does not appear to be any decided advantage in any particular method. Perhaps something may be gained by placing two



Figs. 40.

cranks at right angles so as to be able to work with only two cylinders, if one cylinder be injured, but by proper arrangement of the couplings when each crank has a separate shaft, the cranks could be turned into the position required.

Fig. 41, shews diagrams of three cylinder and four cylinder three-stage or triple expansion engines. In the second part of the figure, (4 cylinder type) the engines are slightly



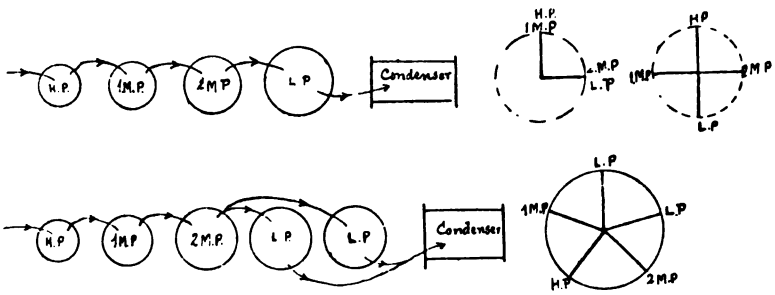
Figs. 41.

inclined to the vertical, two cylinders on each side, and by this arrangement the length taken up by the engines is considerably shortened. It has been adopted in the Thornycroft Destroyers and torpedo boats, and saves much space, and at the same time gives greater facilities for examination of the internal parts of the engines.

Fig. 42, shews diagrams of four cylinder and five cylinder, four-stage or quadruple expansion engines.

Where the height permits, the cylinders are placed one above another, and this way reduces the number of cranks and connections.

The cylinders are separate vessels and if the steam passes through the cylinders in turn, the engine is a *compound* engine. If the steam passes from the boilers direct to each cylinder



Figs. 42.

and thence into the condenser it is a *simple* engine. With both types the steam may be used expansively by adopting a suitable cut off, but as pressures increased it was found that it was more economical to adopt a two-stage type of expansion or compound engine. If a three-stage type of expansion is used the engine is called a triple expansion or tri-compound engine, if four-stages are adopted a quadruple expansion, and so on for any number of stages.

Working expansively in a simple engine is economical until a point is reached when the alternating temperatures in the cylinder, become too great in range, so that a great part of the steam power is lost, by liquefaction and radiation from the internal and external surfaces of the cylinder. Generally a range of 80 degrees is the maximum that can be worked without loss, but at low pressures where the temperature of the steam in the cylinder, approaches the external temperature of the engine room, the losses are not so great and ranges from 100 to 140° are adopted with economy. At the same time it is generally economical to jacket the low pressure cylinder when

adopting a great range of temperature so as to prevent loss from internal causes. The total amount of heat required to convert 1lb. of water from an initial temperature of 92° into steam at 60lbs. pressure is about 1115 thermal units, and to convert the same quantity of water at the same temperature into steam at 200lbs. pressure is 1140 thermal units; or only about $2\frac{1}{2}$°/₀ greater heat is required for nearly three times the pressure, and if we can use this great expansive force economically we can obtain an enormous economy of the engine for a given fuel consumption.

Mr. Seaton gives the theoretical advantages of high pressures as a gain of $26\frac{1}{2}$°/₀ from 30 to 75lbs.
15°/₀ from 75 to 125lbs.
10°/₀ from 125 to 175lbs.

In practice these economies can only be effected by a proper regard to the range of temperature adopted for each cylinder. Thus a compound engine using 140lbs. pressure, shows little economy over one using 90lbs., while a triple expansion engine shews a greater economy than theoretically due, when working at 140lbs., against a compound engine at 90lbs. The actual amount of fuel saved by using a modern triple expansion engine working at 160lbs. pressure, in place of a compound engine, using 75lbs., is nearly 25 per cent.

For pressures over 175lbs., a four-stage or quadruple expansion engine would give the most economical expenditure of fuel, but it is usual in the navy to adopt much higher pressures so as to get the greater power in less space and with less weight. This is a doubtful economy as the amount of extra coal required to give the same *radius of action* (total distance ship can steam with her own coal) considerably exceeds the comparatively slight increase of weight of engine, and the space saved is inconsiderable.

Ratio of cylinder-volumes for given pressures

90lbs. compound, $\frac{\text{H.P.}}{\text{L.P.}} = \frac{4}{21}$ } Cut off at ¼ths. stroke in H.P., cylinders.

120lbs. compound, H.P : L.P. = 4 : 27 }

120lbs. triple H.P. : M.P. : L.P. = 10 : 21 : 54 }

140lbs. triple H.P. : M.P. : L.P. = 10 : 22 : 62 } Cut off at ⅛ths. stroke in H.P., cylinder.

160lbs. triple H.P. : M.P. : L.P. = 10 : 24 : 70 }

180lbs. triple H.P. : M.P. : L.P. = 10 : 25 : 78 }

180lbs. quadruple H.P. : 1 M.P. : 2 M.P. : L.P. = 10 : 18 : 36 : 79

Much larger low pressure cylinders are sometimes adopted and by this means obtain a better degree of expansion and, therefore, economy, but any increase of ratio must be carefully considered in conjunction with the corresponding range of temperature involved, so that it shall not be too great. Equality of strain is sometimes obtained by using two or more low pressure cylinders, and thus obtaining a higher rate of expansion, without any extra strain on the low pressure connecting rods and attachments.

In fig. 43, (frontispiece) the general arrangement of an engine is shewn. It is similar to those fitted in H.M.S. "Daring," "Decoy," "Boxer," and other torpedo-boat destroyers and is of the four cylinder triple expansion type. The framing is very light and strong and the supports consist principally of upright pillars, bracketed where necessary horizontally by cast steel angle plates. The pillars, by an ingenious arrangement, also perform the duty of main bearing bolts. The air pump is worked by levers from the forward low pressure crosshead. The starting and reversing gear is of the continuous motion type, and can either be worked by hand or by steam, by the small engine shewn in front of the figure. The piston rod guides are hollow and a continuous circulation of water is provided for keeping the bearings cool. The slide rod guides are formed by an enlargement of the rod at that part. The crank shaft and connecting rods are hollow and this practice has been followed

wherever possible to save weight and to give greater stiffness and rigidity.

The machinery of torpedo boats and other fast vessels has generally pioneered the designs of that for larger vessels. When it is considered that the question of weight in a small vessel is of the first importance, this appears only a natural outcome. The machinery in some of the torpedo boat destroyers weighs half the displacement of the whole vessel. The enormous power developed with perfect safety, in vessels of the minimum thickness of framing and plating, is only obtained by minute attention to the smallest details in the design of the machinery and boilers.

Fig. 44, shews a plan of the arrangement of boilers, engines and steam pipes which is generally followed in the navy.

In the outline sketch the thick lines show the bulkheads (generally water-tight) between the various compartments and surrounding them.

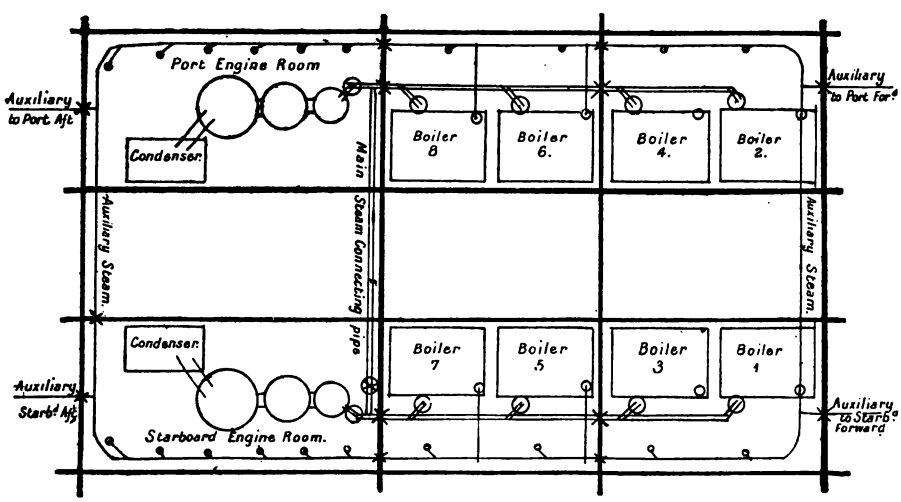


Fig. 44.

Eight boilers are placed in four stokeholds and one triple expansion engine is placed in each of the two engine rooms. The main steam pipes are shewn by double lines, and the auxiliary steam pipes by a single line. Where the steam pipes pass through bulkheads, valves are fitted in each. These valves are generally self-closing and can be worked separately from either side of the bulkhead, (in the diagram they are marked X.)

A cross connection is made between the main steam pipes in the engine rooms and sometimes a similar cross connection is made in the stokeholds either forward or aft. By this means either engine can be worked with any boiler or set of boilers. The main circulating engines, the main feed pumps, and the air pumps when fitted as separate engines generally take their supply from the main steam pipe, but a connection to the auxiliary steam is also fitted.

The auxiliary steam pipe makes a complete circuit of the engine and boiler rooms, branch connections being taken to each boiler and to each engine. For supplying the engines outside these compartments, branches lead forward and aft. In the battle ships there is generally one on each side, port and starboard, but in smaller ships one forward and one aft is generally sufficient.

The exhaust (auxiliary) system of piping generally closely follows the steam system and thus gives completeness and simplicity. Auxiliary condensers are usually fitted, one in each engine room for larger ships, but in smaller ships the auxiliary exhaust steam is usually led into one of the main condensers.

With main steam pipes it is a good practice to so dispose the branches from each boiler that there is no confusion of currents, as the steam rushes towards the engines. With low powers right-angle connections do not affect the pressure much,

but when the fires are forced, difficulty is experienced in keeping the pressures equal in all boilers, and frequently a loss of power takes place from this cause by blowing off steam from some one or two boilers from which the steam cannot pass away readily enough into the main steam pipe.

Separator.—This fitting is frequently introduced into the main steam pipe near the engine regulating valve. Its use is to prevent the passage of water with the steam, into the engines. As will be seen from fig. 45, it is a simple fitting, consisting of a vertical cylindrical vessel, with a diaphram or dash plate separating the upper portion of it. The steam from the main steam pipe enters by the inlet and impinges on the dash plate and the water then falls to the bottom of the chamber, the steam, being lighter, rises, and goes out by the outlet from whence it is admitted to the engines. The water can be drained out when required, by a cock with a pipe connection, to the feed tank, to the condenser or overboard as required. A gauge glass is fitted as shewn in the sketch, so that the water can be seen, and the cock need not thus be opened unnecessarily and so occasion a loss of steam. The separator is a very useful adjunct to the engine, and many accidents from priming or neglect have been averted by its use. With triple expansion engines and high pressures however it is not now frequently fitted, steam traps or some other means having been fitted in its stead. With high pressures a vertical stay is necessary, to strengthen the top and bottom of the separator. Perhaps the difficulty of arranging for the necessary strength without increasing the weight has militated against its use with modern engines.

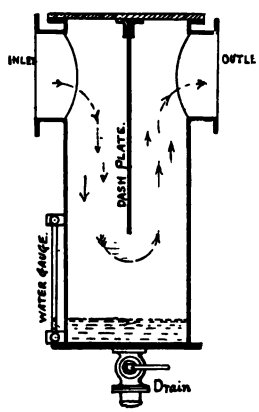


Fig. 45.

It is the usual Admiralty practice to specify that a separator should be fitted in the steam pipe for the dynamo engine.

Condenser.—In surface condensation two objects are in view; one, to obtain the benefit of a vacuum on the main engine, and the other, to keep the water of liquefaction of the exhaust steam, separate from the cooling water, so that it can be used again in the boilers. The re-use of this pure (distilled) water in the boilers, assures freedom from incrustation, or deposition of salts on the heating surfaces. For this reason sea going steamers have adopted this method of condensation almost exclusively.

In fig. 46, H is the condenser, which is generally of cylindrical form, the tubes being horizontal and running from end to end of the condenser body. The circulating water passes through the tubes which are secured to the tube plates which form the end plates of the condenser. The ends are encased by two covers, leaving sufficient space for the circulating water and connections of the proper pipes.

The figure shews a condenser that can be used either as a jet condenser, or as a surface condenser by proper manipulation

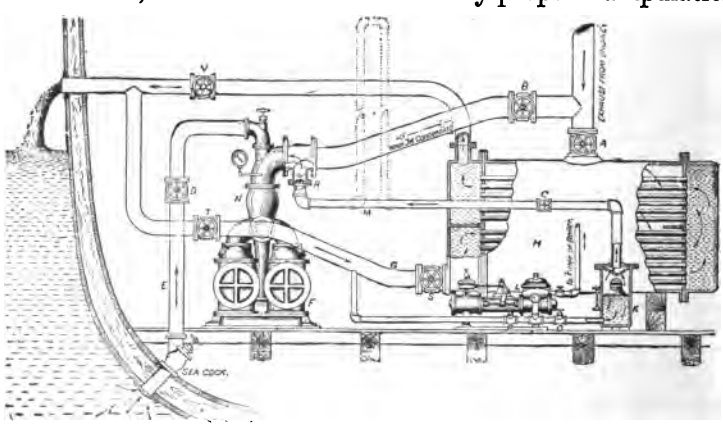


Fig. 46.

of the valve connections. It also shews a special arrangement fitted by the Worthington Pumping Engine Company for combining the use of the circulating pump with that of the air pump, and in this way dispenses with the separate air pump which is usually fitted.

The exhaust steam from the engine is conveyed by the large pipe at the top of the condenser, through the valve A directly *around* the tubes. *Through* these tubes the sea water from the sea-cock is circulated by the pump F, by way of pipes E, G and I. The quantity of circulating water is regulated by the valve D. The condensed steam-water falls to the bottom of the vessel H, and into the hotwell K, from which it is taken by the boiler-feed pump L, and supplied to the boilers. In this arrangement it will be noticed that the feed pump takes its suction, direct, from the hotwell or lower part of the condenser, and not as is usual from the feed-tank, into which the water has been discharged by the air pump.

Air and uncondensable vapour that become separated from the steam when it is liquefied would accumulate, were it not for the inducing action which takes place at N. The spraying water entering by pipe E, maintains the vacuum by entrapping the air, which is conveyed from the hotwell K by pipe M to the cone N. The air thoroughly mingled with the water, falls into the pump, and after passing through the tubes of the surface condenser H, is discharged overboard by the pipe I. The small vapour pipe M is provided with a valve R, as shown, which would prevent the circulating water from entering the pipe, and thus flooding the hotwell and surface condenser, with impure water, if, through any failure on the part of the pump F, the water should rise in the vessel N. An equivalent water check for this purpose may be formed by causing the pipe M, as indicated by dotted lines, to extend to such a height, say 30 feet (which is equal to a vacuum of 30 inches), above the surface of the water supply so that the

vacuum formed in the surface condenser will not be sufficient to cause the water to rise to the summit, and thus reach the hotwell.

This arrangement can be used as a jet injection condenser by closing valves A.C.O, and opening B and P. The boiler feed water, which will be sea water in this case, may be taken from the pipe G, through valve P.

Condenser tubes.—These are generally of brass, and the whole condenser shell and all parts connected with the condenser, through which the condensed water has to pass, are in the best practice made of brass or gun-metal as nearly as possible of the same constituents viz:—at least 70°/₀ copper 1°/₀ of tin and the remainder of zinc. The tubes are fitted into the condenser tube plates fairly tightly, and then screwed glands, (with a slot or square for screwing up), inserted on top of some packing round the tube ends. This arrangement is shewn in fig. 47, and is that usually employed. Sometimes wood ferrules are used, but they are not so satisfactory as the previous method, as the wood is much more acted on by change of temperature or lack of moisture.

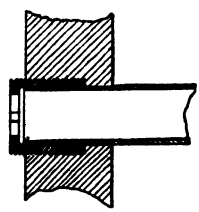


Fig. 47

With tubes of excessive length, it is necessary to support them by means of diaphragm plates.

The tubes should fit fairly tightly in the holes of the diaphragm plate, so as to prevent hammering from vibration.

Air pump.—Originally the cylinder itself was cooled to produce a vacuum, but gradually it became evident that a separate vessel for this purpose would be advantageous, and James Watt therefore introduced the condenser. In this way he attempted in practice, that which he had held in theory, *i.e.*, keeping the steam-cylinder always as hot as possible,

and, connected with the cylinder another chamber called the *condenser* to be kept as cold as possible. Hence it follows that the steam, directly it enters the cylinder, is ready to act with effect; and directly the communication is opened to the condenser, it makes its escape; and by its condensation a partial vacuum is kept in the condenser. At this point another difficulty arises, for it is evident the water would soon fill up the condenser, unless removed as fast as it entered; and besides this, the gaseous matter evolved from the water in boiling, not being capable of condensation, would destroy the vacuum. To provide against this there must be a pump in connection with the condenser, to carry off the water and air as fast as they enter. This pump is the *air pump*. The function of the air pump is therefore to pump the condensed steam and vapour from the condenser, and at the same time to decrease the pressure in the condenser, by continually pumping out its contents. The condenser and air pump are mutually dependent on each other, as a means of reducing the temperature and pressure of the exhaust. The circulating water surrounding the steam chamber as in a surface condenser, abstracts heat from the exhaust steam and condenses it into water. This condensation of the steam reduces the pressure and so on until a point is reached when the maximum amount of cooling has taken place. At this point the air pump plays its part by maintaining the pressure at a corresponding point and thus they mutually assist and depend on each other in performing their proper functions. The air and water drawn from the condenser by the air pump, are discharged into the feed tank, the air then escapes through a vent pipe on top of the tank or pump. From this tank the boiler feed pumps take their suction, and thus the same water is used over and over again.

With a surface condenser and where the glands and packing of the cylinders and rods are good, the amount of air which really enters the condenser is very small, and thus the

air pump could be made much smaller if these conditions could always be maintained, but provision has to be made for emergencies and thus the air pump is generally a large fitting. The most efficient method of working it, is from the main engines by means of levers from one of the crossheads.

Working direct from the piston appears to be unnecessarily complicated in its action. The pump plunger speed is too great, being the same as the main pistons, this does not lead to great pumping efficiency, the stroke is unnecessarily long, and the work thrown on to the piston rod by a bending action caused by this method, frequently distorts the pistons and rods.

Sometimes the air pump is worked by a separate engine. This has many advantages for a vacuum can be maintained at all times (that is, including when the engines are stopped) it thus keeps the engines clear of water and the vacuum enables the engines to be more easily started and reversed. On the other hand the air pump engines must be large and very

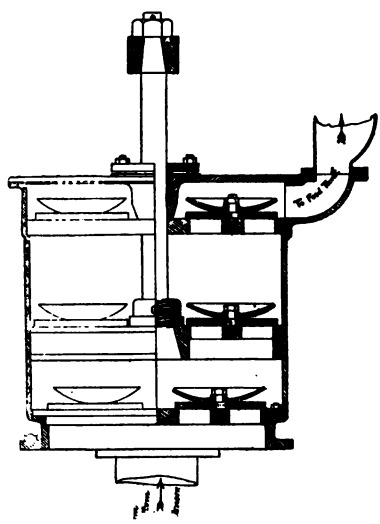


Fig. 48

powerful for driving in this way, and as they are always at work whether required or not, this also adds to the expense of first fitting and to the weight.

Generally a vertical pump worked by levers from the low pressure piston rod crosshead, as shewn in fig. 48, appears to be the simplest method, especially with vertical engines. The volume swept out by the air pump plunger is about one twentieth that of the low pressure cylinder. By a suitable arrangement of levers the stroke can be shortened up to about one third or one fourth that of the piston, and thus the plunger speed can be kept within ordinary limits.

Vertical air pumps are generally single acting and are fitted with valves of india-rubber or metal for delivery plunger and suction.

The pump should be so placed that under ordinary working conditions the suction valves should be covered with water, by being placed at a lower level than the bottom of the condenser. In horizontal pumps this is somewhat difficult of attainment, and to obtain the best results, the air pump is made double acting and placed immediately below the condenser of which the pump chambers form actually a part.

With the Worthington arrangement of combined circulator and air extractor (or pump), the air pump has been eliminated and an arrangement of pipes used for extracting the air by means of a jet. With the ordinary arrangement the feed pumps take their suction from the feed tank, and the amount of work thrown on to the pump as a suction pump, is almost nothing, and frequently the feed tank is on the same level or above the level of the suction of the pump. With the Worthington arrangement however the water has to be drawn into the feed pump, for it must contain as great a vacuum in it as that in the condenser, or the water will not run into it. The extra work thus thrown on to the feed pump must not therefore be neglected. And unless the feed pumps are also most efficient

suction pumps the vacuum must be lowered to their requirements or the feed pumps cannot efficiently supply the boilers.

Fig. 48, shews an arrangement of a vertical air pump in part section: with, delivery valves, bucket and valves, and suction valves. As will be seen the pump is single acting. The plunger is packed with hemp generally, but is sometimes made solid or fitted with a metal ring which may be either solid or cut and fitted with a tongue piece. The valves shewn in the pump, are of vulcanized india-rubber, but more frequently with feed heaters and higher pressures metallic valves are used.

Fig. 49, shews a type of metallic valve known as Kinghorn's, it consists of three plates each about one sixteenth of an inch thick, the two lower plates being perforated with holes *not* immediately over each other. The valves are returned to their seating after lifting by means of a light brass spring. The lift of the valve shewn is about three-eights of an inch.

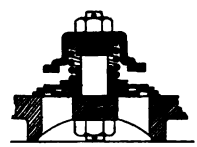


Fig. 49.

Other methods are numerous, one which consists of a series of concentric corrugations on a metal plate being a common method.

The efficiency of the air pump being a very important factor in the efficiency of the engine, every opportunity should be taken of examining, and if necessary refitting the air pump valves, especially those used as foot or suction valves.

Circulating pumps.—For this purpose centrifugal pumps are usually fitted as they are more adapted to this purpose than the ordinary reciprocating pump.

In fig. 50, a type of centrifugal pump frequently used is shewn in section. As the name implies the water is drawn in at the centre part and thrown off at the periphery or outer part. The arrow heads shew the direction of rotation and of

the course taken by the water. There are no valves in these pumps to get out of order and as they are below the water line, the supply or suction pipe keeps the pump chamber

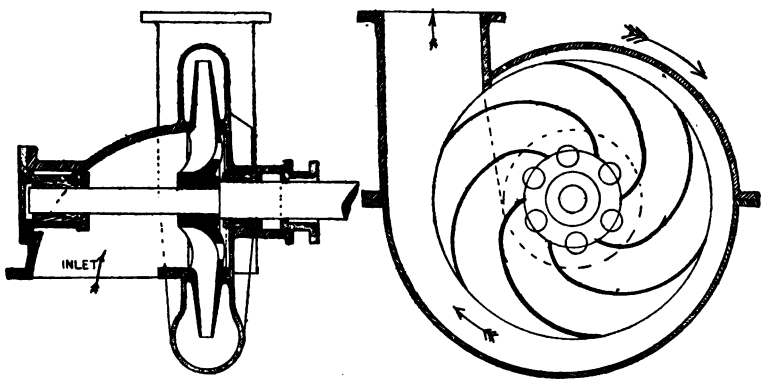


Fig. 50.

charged. The pressure the pump has to exert is very small and consequently a great efficiency is obtained from this class of pump for this purpose.

The impeller is driven by a separate engine, a part of the shaft of which is shewn. The shaft usually runs in lignum vitae bearings fitted at each end of the pump chamber, and a gland is fitted at the engine end to prevent the water leaking through. The small holes in the impeller are made to admit water to the engine side of the impeller, and thus balance any end pressure on the shaft which is set up by the pressure of the water on the inlet side. Usually the water passes *from* the circulating pump *through* the condenser tubes and then overboard. The inlet in the bottom of the ship is fitted with a grating and is sometimes made in the form of a scoop so that the motion of the ship itself will assist the pump.

Circulating bilge suction.—To each pump a connection is generally fitted for pumping out the engine room bilges. There is a non-return valve fitted in the lower part of the bilge and connected by a pipe to the inlet of the pump. When

required for use the spindle of the bilge suction is screwed back and the sea suction gradually closed, and the pump keeping itself charged, will pump out the bilge.

Quantity of cooling water required.—Usually a rise of temperature of about 25° is allowed for the cooling water in the condenser.

The amount of heat in 1lb. of steam at the point of exhaust into the condenser is about 1100 thermal units, allowing for a pressure of about 3lbs., absolute.

Therefore $Q = \frac{1100}{25} = 44$lbs.

If n lbs., of water are used per I.H.P. of the engine, (this varies from 12 to 20lbs., according to the economy of the engine.)

The quantity of cooling water required per *hour* is= 44. n., I.H.P., and the pumps must be capable of pumping at least this amount through the condenser.

If the temperature of the sea water be 80°, the discharge temperature should be about 105°. The absolute pressure due to a temperature of 105° is about 1lb., and therefore a vacuum of about 28 inches should be obtained if the air pump and condenser are efficient.

Usually two pumps are fitted, each capable of supplying sufficient cooling water for all the condensers, and connections are made for use in the event of one breaking down.

The losses which must occur more or less necessarily in a steam engine are as follows :—

1. *Throttling the steam* before its entry into the engine. This may be caused by the stop valve not being fully open, and also by the passages through the stop valve and the steam pipe, between the stop valve and the steam chest being contracted. Sometimes this is called *wire-drawing the steam.*

2. In the steam-chest.

(a.) Radiation of heat from the external surfaces of steam-chest.

(b.) Heat conducted through slide valve rods.

(c.) Steam required to compensate heat radiated from slide valve into the exhaust pipe.

(d.) Leakage of steam through stuffing boxes and joints.

(e.) Leakage of steam between valves and wearing surfaces into exhaust pipe.

3. In the cylinder.

(a.) Loss due to wire drawing caused by slide valves opening and shutting gradually. The wire drawing will be greater if the passages are contracted.

(b.) Condensation of part of the steam during admission, caused by the steam passages, cylinder walls, covers, pistons, piston rods, etc., having been cooled during the periods of expansion and exhaust. Also condensation of some of the steam during the early part of the expansion; this is due to the cylinder not being warm enough to keep the steam at the point of saturation. Some of the condensed steam will be re-evaporated at a low pressure during the latter part of expansion, and will do work on the piston. But this re-evaporation takes heat from the cylinder walls, pistons, etc., causing a fall in the temperature of these parts.

(c.) If the re-evaporation of the condensed steam has not been completed before the release takes place, the heat required for re-evaporating the remaining water will be carried into the exhaust, and thus wasted.

(d.) Radiation of heat from external surfaces of cylinders which are not jacketed.

(e.) Leakage through stuffing boxes and joints.

(f.) Leakage between cylinder walls and piston.

(g.) Waste of heat (steam) in blowing through drain cocks.

(h.) Waste of steam in filling clearance volume at every stroke. This loss can be diminished by a proper amount of compression. It is evident that for economy in compression, it is necessary that the work done in compressing the steam should be less than that required for producing the steam saved by compression.

(i.) As the exhaust steam must pass through passages of limited area, it follows that the pressure of the exhaust will be greater than that of the atmosphere or condenser.

4. In the jacket.

(a.) Loss by radiation.

(b.) An actual steam jacket cannot be so effective as an ideal one because the material of the liner and cylinder is not a perfect conductor, and the surfaces are generally covered with a slight scale or grease which are bad conductors of heat.

(c.) Imperfect drainage of the jacket is a fruitful loss. If the drainage is insufficient, heat must be extracted from the cylinder to heat the jacket steam because the jacket does not perform its proper function. If the drainage is excessive, the waste steam or water is allowed to go without doing any work. The remedy of imperfect drainage appears to be only obtained by proper adjustment of the steam pressure, and drainage of the jacket by means of a *drain-trap.*

(d.) Leakage of jacket steam into exhaust passages.

5. Fall of pressure between the cylinders of compound engines. This loss is compensated by good design and adjustment of proper range of temperature in each cylinder. In practice the compound engine is undoubtedly more economical than the simple engine, and three stage more than the two stage.

6. Loss by exhausting into the atmosphere instead of using a condenser. This loss exceeds the sum total of all the other losses enumerated, and therefore the engine will be considered as surface condensing. The losses in the condenser are very great but a certain amount can be retained by heating the feedwater. The waste heat passes off in heating the circulating water.

7. Mechanical losses.

(a.) Friction between the working parts of the engine. These can be reduced to a minimum by proper adjustment and alignment.

(b.) Energy spent in driving feed pumps, air pumps and circulating pumps.

CHAPTER VIII.

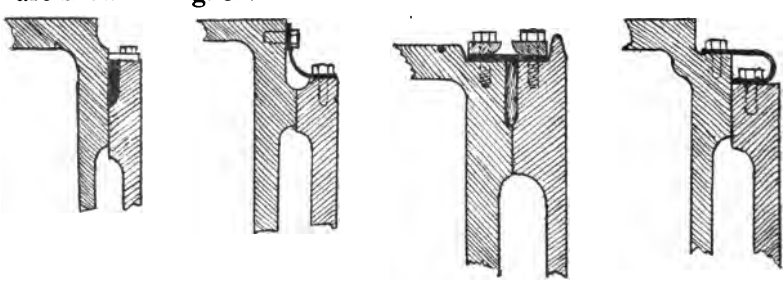
CYLINDERS AND THEIR FITTINGS.

Cylinder liners.—The working surface of the cylinder, is generally made as a separate barrel, which is termed the liner This liner has to be fitted into the cylinder and made steam tight at each end, and special means are adopted to allow for independent expansion. The inner end of the liner is usually flanged inwards, and jointed (as shewn in figs. 51 and 53) to to the end of the cylinder. Wire woven asbestos gives good



Figs. 51.

results as a jointing material. The inner end is thus practically solid with the cylinder, although the asbestos joint gives a very slight room for expansion. At the outer end various means are adopted for making it steam tight, the most commonly used are shewn in fig. 52.



Figs. 52.

One consists of a recess which forms a packing gland fitted with a covering plate. The covering plate being bolted to the end of the liner *only*, so that the liner, when expanding or

contracting in a less degree than the cylinder, can slide on the packing. Other methods used are composed of a copper bellows ring jointed to both the liner and the cylinder, the copper is sufficiently pliable to allow for independent expansion. The cylinder liner must be made steam tight and the jointing must allow for a reasonable expansion (principally but not entirely longitudinally.) The jointing at the outer end should be capable of adjustment and repair without disturbing the liner. Keep rings or other suitable means are always fitted to the bolts or nuts fitted in the interior of the cylinder.

In fig. 53, a sectional elevation is given of a cylinder fitted with a liner. The space between the cylinder and the liner is generally used as a *jacket* for keeping the cylinder warm. The ends and covers of the cylinder are sometimes cast hollow, so that they may be used as jacket spaces, but generally it is considered sufficient to jacket the barrel or working surface of the cylinder only. The cylinder liner is generally made of

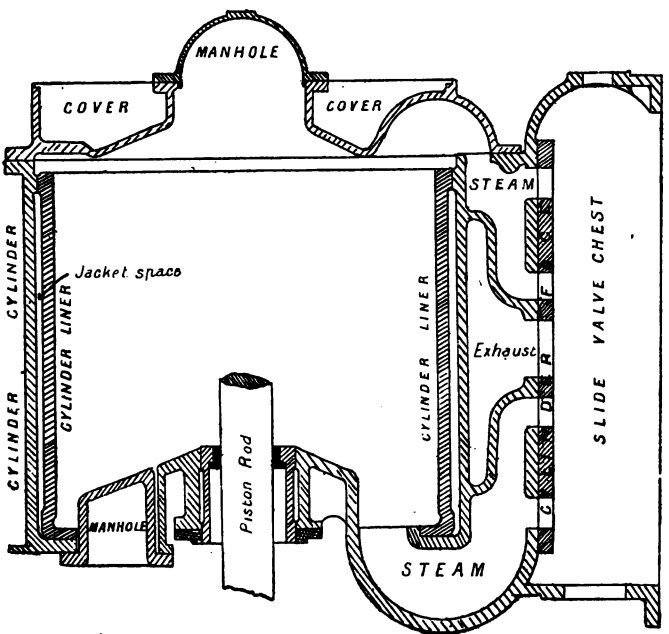


Fig. 53.

hard close grained cast iron, and sometimes of steel. For the cylinder itself, cast iron is generally used, but recently steel has been introduced for this purpose. Steel is used wherever possible in making engines, and as experience is gained its use is increasing. *Fluid compressed* steel is sometimes used for liners.

The *cylinder face* is generally a separate fitting. It forms the working face on which the slide valve moves. It is usually secured to the cylinder face proper, by counter sunk or cheese headed bolts. The false face can thus be removed and refitted without removing the cylinder, or it can be taken out at any time and trued up when it is found to be worn unevenly. The false face is generally made of cast iron, close grained, but sometimes metals such as phosphor bronze and various others are used.

The whole of the outside of the cylinder is lagged with asbestos or some other bad conductor of heat and covered in by iron or brass sheeting and sometimes mahogany, but brass is preferable or carbonized (blue) steel, as either can be kept cleaner and if used with ordinary care lasts much longer.

Piston.—Fig 54, shews a cast iron piston of the flat or hollow type, which was frequently fitted and is still used in many large cylinders. The modern practice is however to fit

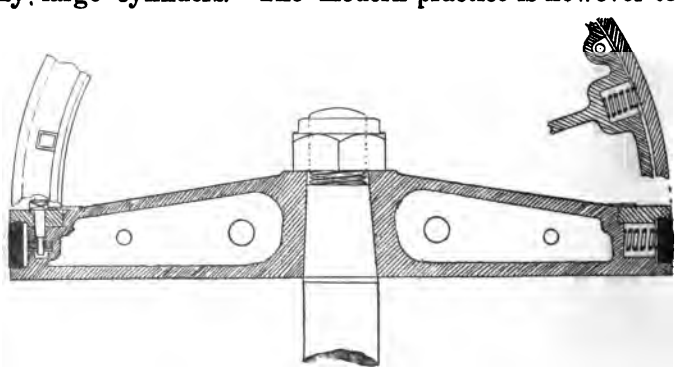


Fig. 54.

steel pistons, made in a cone shape to give strength and stiffness, these are much lighter and stronger and have gradually superseded the old fitting of cast iron. This method is shewn in figs. 55, and 56.

Metallic packing for pistons.—This is fitted as a means of keeping the piston steam tight, and various forms have been

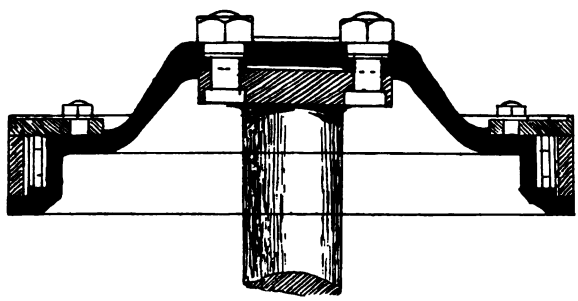


Fig. 55.

adopted. For vertical engines, *Ramsbottom rings*, fig. 56, are generally fitted and give good results. For horizontal engines however without tail rods, when the weight of the piston is practically taken on the ring, a wide phosphor bronze ring is used, as in fig. 54, and 55, the ring being cut diagonally and a tongue piece fitted. To press this type of spring out to its work, coach springs and spiral springs are used, the latter are preferable, being less liable to fracture and easier of adjustment. In adjustment care should be take not to put too great a pressure on the spring, and also that the pressure should be distributed evenly. The packing rings should be a good fit into the piston so as to be fairly steam tight on its edges, but at the same time they should be free enough to have room to expand as the ring wears down.

The *junk ring* figs. 54, and 55, is fitted to the piston, to keep the packing ring in place, and also to have convenient access for examination without removing the piston from the cylinder, and a *guard ring* is fitted to prevent any junk ring bolts from slacking back.

The piston rod is fitted to the piston in various ways shewn in figs. 54, 55, 56, but the simplest method is usually adopted, viz:—a coned, shouldered end, fitting into the piston with a nut at the back end. A key is usually fitted to prevent the piston turning on the rod. A shoulder should always be

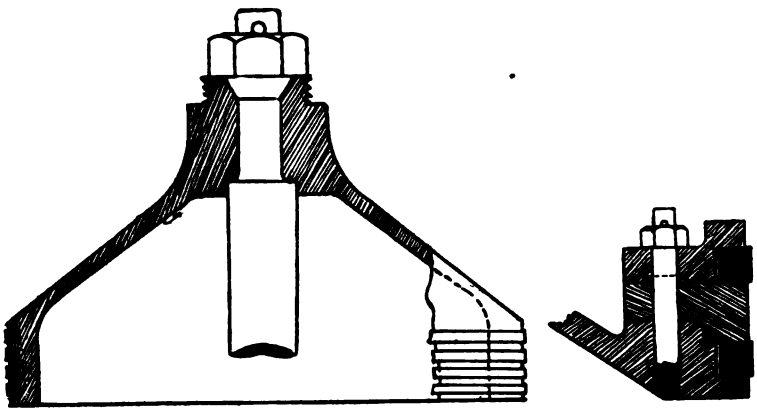


Fig. 56.

fitted, and the inner corners rounded so as to get as much strength as possible at this point, and when fitted in this way the rod need not be coned, but made parallel where it passes through the piston. The piston rod nut is always secured from slacking back, by some approved method.

Packing glands are fitted, where the working rods pass through the cylinder, to prevent any leakage inwards or outwards. The gland and parts which are likely to come in contact with the rod are made of metal generally brass, but white metal of the Babbitt type is now frequently fitted. For this reason a *neck ring* of the same metal is generally used as shewn in fig. 57. To facilitate adjustment of the packing when under weigh, the gland is fitted with a cogged ring, to suit cogged nuts on the gland studs, so that they can also be screwed up evenly.

Various types of packing are used but, it should always, when metallic, be of the floating kind, which gives room for

lateral movement of the rod. Allen's combination packing made of a white metal is of this kind and frequently fitted. Much depends in fitting packing as to whether the rods are perfectly round, and run fairly truly in line, and if this be so and the packing is well fitted and properly adjusted, good

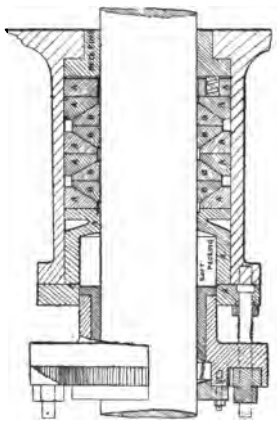


Fig. 57.

results should be obtained. The economy of the engine depends to a certain extent on the efficiency of the packing. If too tight, a great strain from friction is brought on the engines, but if too slack, great inconvenience and loss is experienced from blowing steam and water away which cannot be recovered. The packing for slide rods is similar.

In fig. 57, which shews the packing known as the Combination Metallic Company's, the arrangement by which it is made *floating* is shewn. Gun metal coned rings made in sections A,A, form the seating for the working rings, made of white metal B,B, and coned in an opposite manner. When the steam is not on the engines these rings are kept up to their place, by means of spiral springs of special shape, suitable for their position, the end view of one of the springs being about 2 inches long and $\frac{3}{8}$ths of an inch wide, and curved to suit the shape of the ring in which it is placed. The neck ring is not made a very tight fit in any engine so that a little pressure

leaks past it, and enters the recess between the neck ring and the ring containing the springs. This pressure relieves the springs of their work to a great extent, and so the pressure on the cones is made very nearly proportional, to the work that has to be done in keeping them tight on the rod.

Sufficient clearance between each pair of white metal rings is allowed, for wear and consequent tightening of the glands. The gland next the metallic packing is generally packed with round asbestos. The outer small gland is packed with soft gasket, and it serves to retain any oil or water lubricant on the rod.

Relief or *Safety* valves are fitted to each cylinder, the springs being set to allow the valve to lift, at a few pounds above the working pressure in the cylinder. When, from any cause, an extra pressure or an accumulation of water gets into the cylinder it can escape. In the case of water, when the *compression* is great the slide valve has closed the port to exhaust, some time before the end of the stroke, consequently there is no escape in that direction, and water being almost incompressible some relief is necessary. In vertical engines a relief valve is usually fitted to the bottom of the cylinder only, a safety valve being fitted on top of the slide casing in addition.

Drain cocks are also fitted for relieving the cylinders of water and pipes are led away into the condenser or hot well. In vertical engines the cocks are fitted at the lowest part of the cylinder and of the slide jacket. These cocks are usually kept open, until the engines are well under weigh, and if the drain pipes are led into the condenser, no inconvenience is felt from the presence of a large body of vapour and steam in the engine room.

Regulating steam valve.—Fig. 58. With the introduction of higher pressures it became necessary to use balanced valves for this purpose, to facilitate handling the engines. The

balancing is generally obtained by making two valves on one spindle, the inner valve being somewhat smaller in diameter, so as to admit it through the outer valve seating. Steam is generally admitted from the boilers between the two valve seatings, so that there is a slight resultant pressure in the direction of opening the valve. The valve box is now

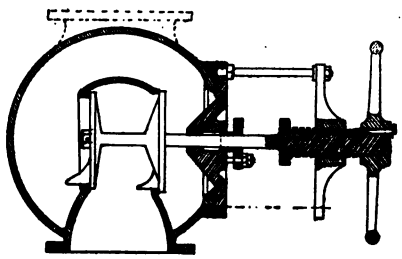


Fig. 58.

made in the shape of a globe, thus getting the greatest possible strength and volume for the smallest weight. In the Navy all valves and casings are of special brass, and it is desirable that a still more reliable material for the casings should be used for higher pressures.

A throttle valve, regulated by a governor, was a common fitting in addition to the regulating valve. It consisted of a plane flat disc hinged at its diameter. The hinge pin formed a spindle on which a lever could be attached outside the steam pipe or valve casing. Governors have given little satisfaction for the main engines and although some such arrangement is desirable, no known method has been found entirely reliable when the ship is rolling or pitching considerably.

Indicator cocks.—(Fig 59,) are fitted to the cylinder and for perfect accuracy one should be fitted for each end, but

generally only one is fitted, on a pipe connected to each end.

The cock is capable of being put in communication with either end as required. A system of levers is also fitted for use



Fig. 59.

with the indicator, one of which on each engine is sometimes utilised for working the revolution counter.

Sight feed lubricators.—are sometimes fitted for the main engines, but as they are now considered unnecessary their use is being discontinued.

To assist in starting the main engines *Bye-pass or Auxiliary starting valves* are fitted. These take steam direct from the main steam pipe, and admit direct to the medium or low pressure receivers. A separate valve is fitted for each

receiver. This is a considerable advance on the old system of admitting steam, as required, to the particular side of one particular piston, which was liable to cause much confusion and delay in inexperienced hands. The receiver starting valves are more certain in their action, and as the steam cannot be admitted by their use, to the wrong side of any particular piston, the engines are not held in any position. This was a frequent experience with the old single ended arrangement of admission to the piston direct.

In a few particular instances the Bye-pass valve would not be suitable. Thus, in a two cylinder compound engine with the cranks set at right angles; if the H.P. crank is on the dead-centre and consequently the L.P. crank at about half stroke, steam could not be admitted through the slide valve by the bye-pass to the piston unless the cut-off is later than half stroke in the L.P. cylinder. This is an exceptional case, as the cut-off in the L.P. cylinder is generally later, frequently at three-quarters stroke.

CHAPTER IX.

THE SHAFTING AND CONNECTING RODS.

Piston rod crosshead and guide.—The piston rod is fitted to the piston as shewn in figs. 54, 55 and 56, and in special instances by other means, but generally one of these methods is used.

The pressure exerted on the piston is communicated to the piston rod and consequently the rod is alternately subject to compression and tension. This has to be allowed for in designing the size of the rod, by considering its strength as a pillar in compression as well as a rod in tension. The rods are generally made of steel this being the most suitable material. From the piston rod the pressure is transferred to the crank by means of a connecting rod. By reference to fig. 38, it will be seen that the connecting rod is not always in line with the piston rod, but that there is generally an oblique action. Consequently the whole pressure is not transferred to the connecting rod, and a certain portion has to be taken on a guide, or the piston rod would be subject to a bending action.

The piston rod with the slipper attached is shewn in the right hand fig. 60, the slipper generally being made solid with the rod and having adjustable rubbing pieces of white metal fitted as in sketch. These rubbing pieces are dovetailed into a gun metal slab, which is secured by bolts to the piston rod end. Provision is also made for going astern when the bending action would tend to lift the slipper. The sketch shews a gun metal bearing for this side. In some types of engines the piston rod has two slippers, one on each side of the rod and perhaps this is preferable for some reasons, but when it is

seldom that a ship is required to go astern for long periods, the method shewn in fig. 60, is quite sufficient. The connecting rod in this type is fitted with a forked end, and a pin, which is received in the bearing shewn. The *gudgeon* bearing, as this is called, is generally of gun metal or of gun metal lined

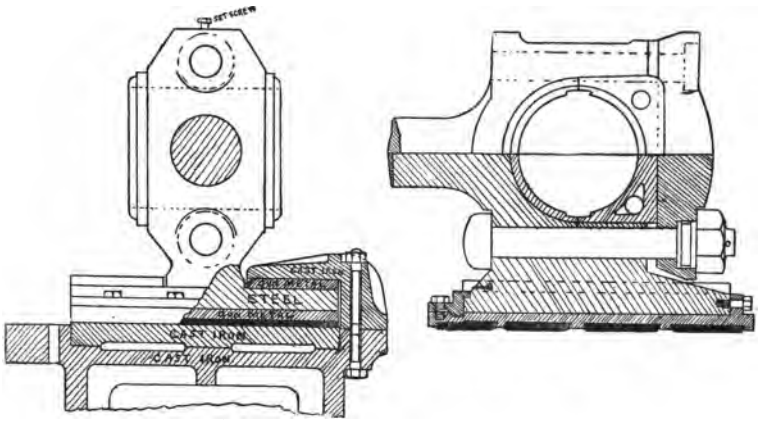


Fig. 60

with white metal. The brasses are secured in place by a steel cap and two bolts. In some cases the gudgeon pin is fitted in the piston rod end, and in this case (see fig. 61) the bearings will be two in number, one on each end of the fork. There appears to be no advantage in either system. The guides are generally of cast iron or steel. Iron, case hardened on the

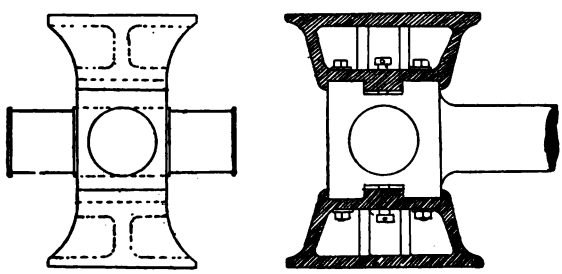


Fig. 61.

surface, is generally used for the gudgeon pin, but where the bearing is of white metal, steel is preferable. Steel and gun metal do not give good results as a mutual bearing surface,

where, as in the case of gudgeon bearings they are subject to moisture. Corrosive action generally takes place due to a species of galvanic action. By making the pins a little larger, the same strength may be obtained with good iron, and the liability to pitting is considerably less. Arrangement is generally made for inserting a liner for taking up the wear on the guide surfaces, so as to keep the piston rod central and in proper line.

In fig. 62, a type of *crosshead* used for return connecting rod engines is shewn. The piston rods, two in number, are

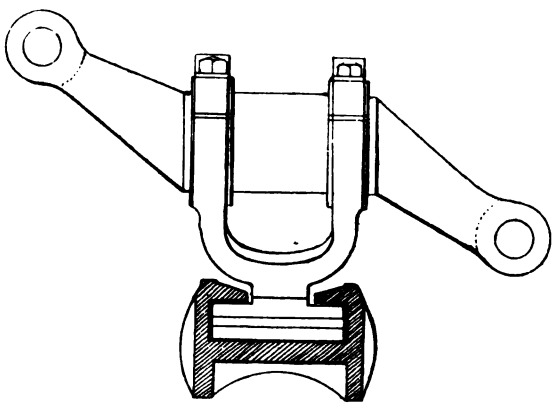


Fig. 62.

secured to the ends of the two arms shewn, the connection being similar to that at the piston end. The connecting rod journals on the gudgeon pin in the middle.

In figure 63, a common type of *connecting-rod* used is shewn. The fork end contains the gudgeon pin, which works in a bearing at the end of the piston rod. The crank end has brasses fitted, which are lined with white metal. The white metal strips are shewn in black, in the sectional part of the sketch. The connecting rod for direct acting engines, should have a length from centre to centre of bearings, of at least two strokes of the engine. A long connecting rod has the

advantage of a better leverage. The direction of the force acts more nearly vertically to the crank, and consequently less force is wasted in keeping the crosshead on to the guide.

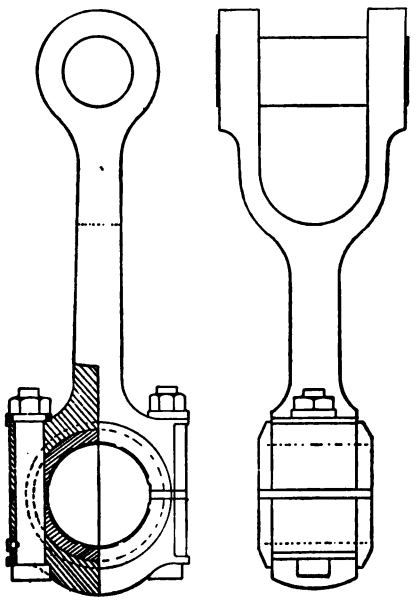


Fig. 63.

In considering the motion of the ordinary direct-acting engine, the various forces and resistances acting in various directions must also be included. In fig. 64, a diagram is given of the forces with their directions. The full lines show any position of the crank, A C, and the connecting rod, B C, on the down stroke. Suppose the total force, or pressure, exerted on the piston to be P, then this force, P, acts in a line, B^1 B. At B, part of this force is transferred to the connecting rod, and to alter the direction of the force into this line, a variable resistance, G, is necessary. G is the resistance of the guide and acts in the direction shewn by the arrow, that is perpendicular to the guide surface. At the point, B, we have three forces, which may be momentarily considered in equilibrium. Denote the angle C B A by θ.

Then, G = P. tan θ.

At the top and bottom of the stroke the angle θ vanishes and consequently tan θ = zero.

Therefore, G = zero at these points; and G will be a maximum when, tan θ, is a maximum; that is, when θ, is a maximum. A little consideration shows that, θ, is greatest when the angle B C A, is a right angle.

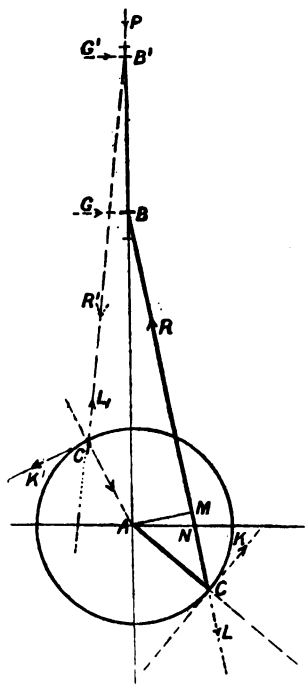


Fig. 64.

The amount of rubbing surface on the guide and cross-head must be made, of an area, suitable to the *maximum* pressure G.

Again, the force, R, acting on the crank at the point C, is equal to $\frac{P}{\cos \theta}$ and the other forces acting at C, are a resistance CK perpendicular to the crank arm and resistance C A along the crank arm. These three forces may be considered

as momentarily in equilibrium, and the actual force used in rotating the crank is along K C and is equal to the resistance in that line.

Let the crank when in any position, A C, make an angle C A B equal to x with the vertical line; and

Let A C = b, B C = a

Draw A M perpendicular to B C.

Then, if P be acting downwards, at B, the turning moment at C

$$= \text{R. A M.}$$
$$= \text{R. b. } \sin(\theta + x)$$

$$\text{But R} = \frac{\text{P}}{\cos\theta}$$

Therefore, the turning moment is

$$= \frac{\text{P. b. } \sin(\theta + x)}{\cos\theta}$$

And as, b, and a can be measured, the angles θ and x can be calculated for *any* position of the crank. From which the turning moment can be found at any required position of the stroke.

Similarly, at any point B_1 when the piston is on the up stroke, when the force, P, is pulling upwards, the turning moment can be found. If the engines are moving in one direction the crosshead also presses in *one* direction on the guide, but if the engine be reversed, the crosshead presses in the opposite direction, and consequently the guide must be fitted in such a way, that it may take a pressure both front and back. This is shewn in figs. 60 and 62.

By the applicatian of higher mathematics it may be shewn, that when the pressure on the piston is constant throughout the stroke, no power is lost by using a crank. This investigation shews that the result is exactly *the same as if the power had acted through the diameter of the crank circle, without the intervention of a crank.* In actual practice

the pressure, particularly with an early cut-off, is variable. By measurement of the pressure at intervals, on the indicator diagram, and calculating the turning moment at each corresponding position of the stroke, a curve of turning moments can be constructed. These *curves of crank effort*, as they are usually termed, are very useful for various purposes in the design of machinery.

The curves for each crank are calculated from the theoretically expected diagrams, and these are compounded.

A compromise is then made with other details so as to obtain as nearly as possible a uniform turning moment or crank effort.

In fig. 65, a **crank shaft** is shewn with two cranks almost opposite each other, and having the middle web common. The crank shaft is generally made hollow, and similarly the crank pins are made hollow. By employing hollow shafting, greater strength and less weight is obtained. Practically hollow shafts and pins are made very slightly larger in their outer diameter, and the hole is bored leaving about from $1\frac{1}{2}$ to 2 inches of metal on each side. The slightly larger shaft gives a greater bearing surface, so that the pressure per unit of surface is lowered, and consequently adds to the efficiency, as a proportionately large bearing surface is less liable to overheating than a contracted one.

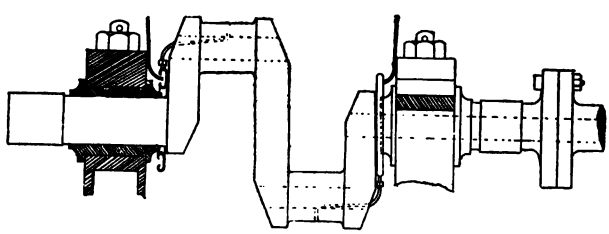


Fig. 65

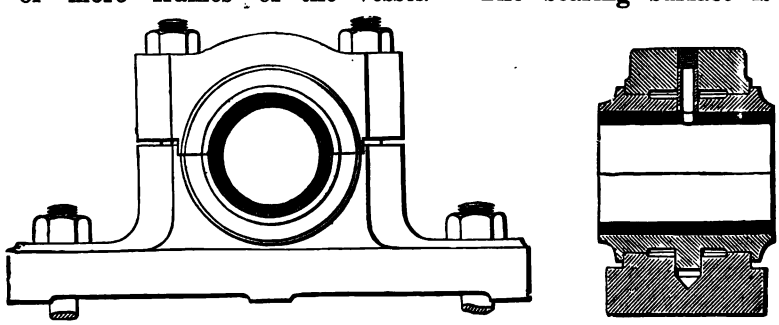
The hole in the crank pin is utilised for *lubrication*. This is shewn in the figure. The lubricant runs down a small

pipe into a double groove which is fitted on to the side of the crank. The centrifugal force given to the lubricant forces it through the pipe leading to the interior of the crank pin, and from here it finds its way through an oilway on to the bearing. Grooves are cut in the bearing to distribute the lubrication evenly.

The crank shaft revolves in the *main bearings*, two of which are shewn, one being in section. The bearing surface is generally of white metal; this practice is almost universal.

The main bearings are supported by framing built on to the frames of the ship.

Plummer Block.—The main bearings only support the crank shaft itself, and the weight of the propelling shaft must be supported at suitable distances to maintain proper alignment. Unlike the main bearings, which have to take a strain upwards as well as downwards, the plummer block generally has only the dead weight of the shaft to support. The plummer block shewn in fig. 66, is itself supported on two or more frames of the vessel. The bearing surface is



Figs. 66.

generally of white metal, and in some cases the upper part of the block is merely a cap and does not come in contact with the shaft. The old practice was to use tallow, as the lubricant, for plummer blocks and some main bearings. This is however greatly superseded by the ordinary syphon oil lubricator, and

as mineral oil, which is generally used, is now very cheap the tallow method has nothing in its favour. A better bearing surface can be maintained with oil as the tallow, which contains a large proportion of water in itself, sustains other water and vapour and produces pitting and other roughness in the shaft.

Thrust block.—When the propeller moves, it exerts a pull or push on the propeller shafting, by which the ship is moved. Some means must be provided for transferring this force to the ship itself, or unknown strains would be produced on the engine framing, and would result in disaster. With screw propellers this force is transferred through the medium of the thrust block, of which a type is shewn in fig. 67. On the shaft itself several collars are formed, and turned accurately to fit into recesses in the block. In the type shown the block is lined with white metal, and the outer casing is made hollow

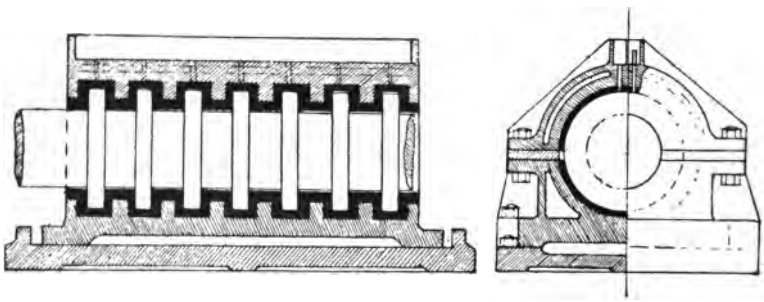


Fig. 67.

so that a continual circulation of water can be maintained, to keep the bearing cool under all conditions. The block is secured to a seating plate, which rests on several frames of the ship, and is strongly secured by means of tie beams and girders longitudinally, so as to distribute the thrust pressure over a sufficient amount of the plating and framing of the ship. The block can be adjusted to a small extent by means of taper keys.

Sometimes the bearing surface of each collar is made adjustable, but it does not appear to have any great advantage,

and adds to the cost of first fitting. If the original fitting is good and the metal fairly homogeneous, the type, shewn in fig. 67, should give as good if not better results, than one which leaves so many opportunities for mal-adjustment.

Stern shaft or tail shaft.—The after part of the propeller shafting, abaft the after coupling which is fitted inside the ship, is made about ten per cent stronger than the remaining part. This part of the shafting would be very difficult to repair, in case of accident, and a bad fracture at this part might endanger the safety of the ship. It is generally made stronger for this reason as well as for reasons of possible strains which may be brought on it from alteration of form or shape of the ship. The shaft passes through a tube built as part of the ship, this is called the *stern tube* and is shewn in fig. 68. The ship about this tube is specially strengthened and stiffened for the purpose. Generally, the inboard end is attached to the transverse framing, and frequently this frame forms a water-tight bulkhead between two compartments of the ship. The bulkhead is stiffened by rings B and C, and the tube secured to the outer ring C which is of angle iron. From the after coupling the shaft is sheathed with gun metal or brass F, the sleeve piece being cast or shrunk on to the shaft. This casing forms a bearing surface for taking the weight of the shaft. Lignum vitæ strips are fitted into a gun metal casing, and this casing is secured to the tube. The *lignum vitæ*

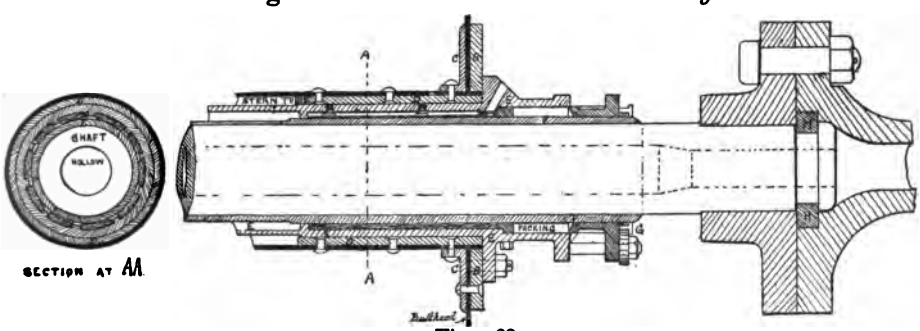


Fig. 68.

forms the bearing, for the stern shaft sleeve to work on. The external water is allowed to circulate among the wood strips, and to prevent the passage of water into the ship, a gland is fitted and packed with soft packing, generally gasket well soaked in tallow. The *stern gland* G, is generally fitted with a cogged ring and nuts, for facilitating adjustment. The gun metal casing E, forms the receptacle for both the packing and the lignum vitæ strips. A cock is fitted so that a little water may be allowed to run through between the strips. The *stern coupling* is sometimes made in the form shewn, H H, being a ring cut in halves. When the bolts are slacked back, the coupling can be parted and the rings taken out. It is convenient as the coupling on the after or stern shafting, can be removed, and after this is done the stern shaft can be withdrawn outboards. A similar bearing of lignum vitæ strips is made at the after end of the stern tube.

In twin screw ships, it is necessary to support the shaft outside the ship, this is done by means of a *bracket* which is fitted just in front of the screw, fig. 69. The bracket is fitted

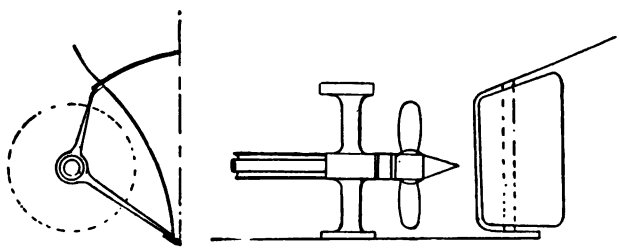


Fig. 69.

with a lignum vitæ bearing, similar to those in the stern shaft. The upper end of the bracket is generally secured to the protective deck, (where one is fitted), and the lower end to a shoe plate fitted round the keel. The space between the propeller boss and the bracket is cased in, and covered with zinc as a protection against galvanic action. The after part of the propeller boss is also protected in the same way.

For small ships white metal is sometimes used instead of lignum vitæ.

Repairing worn bearings in position.—Messrs. Dewrance, the original proprietors of Babbit's metal, give the following directions for filling bearings in place.

In order to prevent the metal adhering to the shaft, and give the necessary clearance when finished, a piece of writing paper, well greased, is tied round the journal.

The shaft is packed up to the original level by laying a piece of the metal between the shaft and bearing; and if there is any spac where the metal might run out at the ends of the bearing, it must be filled up by winding oiled paper or string round the shaft. The metal is then poured into the lower bearing fig. 70.

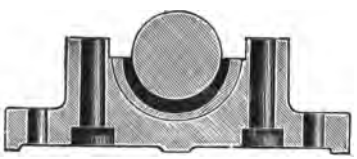


Fig. 70.

Strips of oiled paper are then laid on the side, to divide the metal in the upper bearing from that in the lower, also to pack up the bearing sufficiently, (fig. 71). The metal is poured

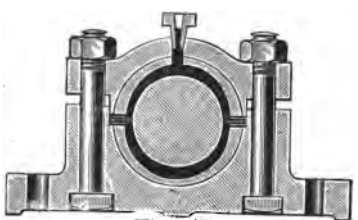


Fig. 71

into the upper bearing through the oil-hole, which is then drilled out, and an oil channel is cut three quarters the length of the bearing.

Great care must be used to see that everything touched by the molten metal is quite dry and warm; as pouring it upon any cold or damp surface causes it to fly.

For emergencies and at other times this is a useful method.

CHAPTER X.

THE SLIDE VALVE AND ITS MOTION.

Slide Valve.—In chapter I. it was explained how, by the addition of heat to water, and the consequent formation of steam, the piston could be moved. In an ordinary reciprocating engine it is necessary that the piston should move in opposite directions alternately, and that the extent of movement should be limited in each direction. Therefore it is necessary to have an automatic arrangement by means of which the pressure can be admitted to each side of the piston, alternately, and at the same time allow the pressure to escape from the opposite side of the piston and thus decrease the resistance on that side. This is done by means of the slide valve. From its peculiar position as the distributor of the work, the slide valve is the most important of the elements of a steam engine, as by its means all the processes of admission, expansion, cut-off, compression and exhaust are produced by its proper motion.

It will be necessary to consider the relative motions by means of an example and for this the *common slide valve*, shewn in fig. 72, will be used. A is the steam port admitting steam to the upper side of the piston, B is that admitting to

the lower side and C is the exhaust port, all these are rigidly connected to the cylinder in which the piston works. V is the slide valve which is moved up and down on the face of the cylinder A B. In the valve V is a hollow space E opposite the exhaust port C. Steam pressure is admitted by the *regulating valve* to the space round the slide valve, and the pressure keeps it close up to the cylinder face. Now if the valve be moved downwards by means of the rod R, the port A will gradually be opened and steam admitted to the upper side of the piston, at the same time the lower side of the piston will be in connection through the port B and the hollow of the valve E with the exhaust port C. Similarly for the upstroke, and continuing in this way alternately the piston rises and falls, according as the steam pressure is distributed by the slide valve.

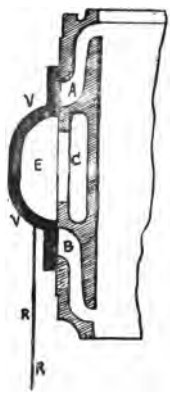


Fig. 72

The piston is, by means of the piston rod and connecting rod, connected to a crank arm on a shaft, and thus the piston moves a certain distance each way from its centre position. The extreme distance the piston moves is called the stroke or travel of the piston.

By reversing the means of obtaining the movement of the crank, a crank can be made to move a reciprocating piece, and thus produce the motion required for the slide valve, and by making the length of this crank arm, the correct one, obtain the proper travel of the slide valve.

This is how the motion is obtained in the ordinary engine, but an eccentric is usually substituted for a crank for producing the motion of the valve. The eccentric is however only a crank fitted in a special way as will be seen in fig. 73, which shews an eccentric, with its strap and rod.

The *radius of eccentricity* is the length of the crank, and therefore one half the *travel* or stroke of the slide valve. As the shaft revolves the action of the eccentric will produce

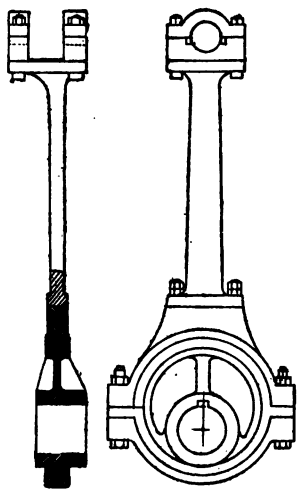


Fig. 73.

the motion of the valve, and thus admit and exhaust steam to the cylinder.

For the proper teaching of the motion of the slide valve and the effect produced on the piston, a working model is advisable but once understood it gives no further trouble. It may however be shewn in a series of figures, but a working model is clear and can produce no possible errors of position, which a sketch on a blackboard frequently does, and in this way leaves a confused idea in the mind of the student. In Engineering Works an engine is usually available for the purpose, and the student can follow all the motions of the engine itself by turning the crank by hand, and watching, the ports, and, the slide valve move in conjunction with the crank.

Lead.—The amount of opening of the port to steam, before the piston commences its stroke is called the lead of the valve.

It is found advisable to give a certain amount of lead to every slide valve, to produce smoother working of the engine, and therefore to produce this lead the position of the eccentric is advanced before the position of the crank, to thus obtain admission and exhaust earlier.

Lap.—The lap of the valve is the amount the valve overlaps the steam port, when the valve is in the middle of its stroke. The amount of overlap on the steam edge is called the *outside* or *steam lap.* If there is overlap on the exhaust edge of the valve it is called *inside* or *exhaust lap.*

Exhaust lap is very small in triple expansion engines. The effect of giving a valve lap is, that to obtain the same amount of opening to steam, the valve must be moved farther from its middle position, or in other words, the travel must be increased. At the same time to obtain the same lead the *angle of advance* of the eccentric must be still further advanced, and consequently all the movements of the valve will be earlier than before.

The *angle* of *advance* is best seen from the fig. 74. Where O P is position of crank.
O L is the outside lap.

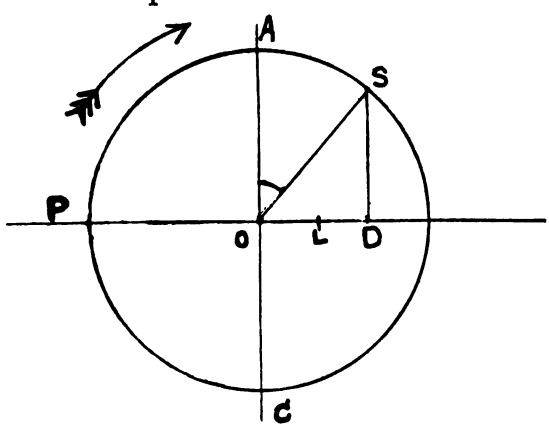


Fig. 74.

L D is the lead of the valve.
Draw D S perpendicular to O D.
O S is length of eccentric radius.
Then O S is position of eccentric arm,
and the angle A O S is the angle of advance. It may be defined as the angle at which the eccentric radius stands, in advance of the position, that would bring the valve to its mid-stroke—when the crank is on the dead point. *i.e.* in line with OP.

Following up the motion of the valve with respect to the crank, it will be seen that the points of admission and cut-off of the steam, are governed by the steam edge of the valve, while the release and compression are governed by the exhaust edge.

Zeuner's Diagram.—All the motions of the valve may be illustrated geometrically. Thus, take XX^1, YY^1 at right angles to each other intersecting at A. (Fig. 75). Through A draw P A R so that the angle X A P is equal to angle of advance. Make A P = A R = radius of eccentricity so that P R

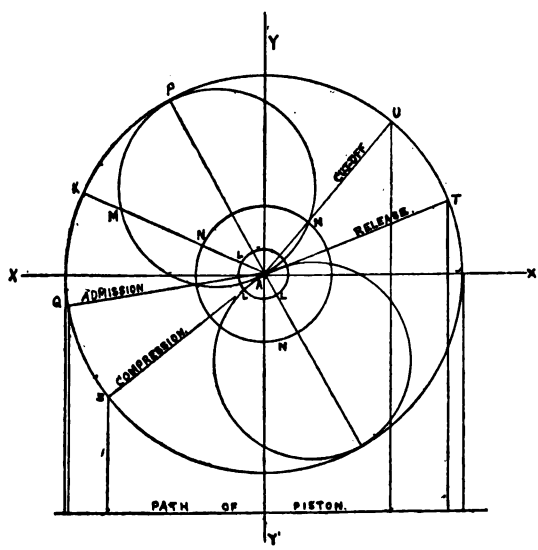


Fig. 75.

= travel of valve. Describe circles on A P, A R as diameter. Describe circle with A P as radius to represent path of crank pin. Describe circles N N N with radius equal to the outside or steam lap and L L L with radius equal to exhaust lap, from centre A.

Take any position of crank A K. Then A M is the distance the valve has travelled, M being the point where A K cuts the valve circle A M P. M N is the opening of the port to steam and M L is the opening of the exhaust port.

Similarly A Q is position of crank when admission commences.

„ A U „ „ „ „ cut-off takes place.

„ A T „ „ „ „ release commences.

and A S is position of crank when compression begins.

Many interesting geometrical problems are founded on these principles and their application when linking up gives many details which are instructive and exposes in some cases errors which might not otherwise be observed.

If there is no inside or exhaust lap, A T, A S will be at right angles to P A R.

The position of the eccentric is generally found from a Zeuner's diagram theoretically, and then fixed temporarily in this position on the shaft, and the exact readings of the valve taken from the crank in its various positions. Any requisite alterations are made before the eccentric is keyed to the shaft. By putting the crank on each dead centre alternately the amount of lead of the valve will be seen for top and bottom stroke. Generally the lead at bottom is made slightly larger than at top, experience having shewn that it prevents shock to the engines at the bottom of the stroke, from the descending weights.

The position of the valve on the rod is altered if necessary, to give the necessary lead top and bottom. The position of the eccentric on the shaft does not affect the lead unequally

but only its amount so that from an approximate position of the eccentric on the shaft the correct position on the rod may be obtained.

To reduce the amount of travel of the slide valve and also to obtain a quicker cut-off and less gradual action, generally slide valves are made *double* or *treble-ported* for large engines (figs. 76 and 77). Their action is exactly similar to the single ported valve, but by introducing two or three ports, the *quantity* of steam admitted can be doubled or trebled, for about the same movement or travel of the valve. The back of large flat valves, is also made flat so that a ring may be fitted

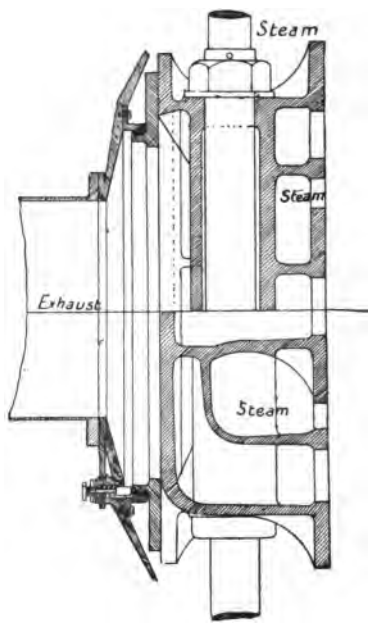


Fig. 76.

on which the valve can slide. The annular space thus enclosed is connected with the exhaust, and thus instead of the whole pressure of the steam being on one side of the valve only a small portion only is allowed to exert a pressure.

These rings are called *relief* or *vacuum rings*, and they reduce the working friction considerably. With high pressures piston valves are now fitted, and as will be seen they have not the tendency to create friction in this manner. In fig. 76 is shewn a slide valve in which the vacuum or relief ring form the exhaust pipe, thus saving much space and weight.

The method of keeping the ring tight is simple, consisting of ramsbottom rings as in a piston. It was found that the copper or steel flange system produced under various temperatures, unequal pressure on the back of the slide valve, and consequently the piston spring fitting was introduced and gives satisfaction. Small spiral adjusting springs are fitted, so that the slide valve should not jump off the cylinder face, a common occurrence when these are badly adjusted and under certain conditions of working.

To support the weight of the slide valve and rod, *balance pistons* are also fitted, (see fig. 77). They are pistons working in cylinders placed immediately over the slide valve, in vertical engines, the lower side of the piston is open to the steam pressure and the upper side is connected to the exhaust pressure. The piston also acts as a guide for the slide valve rod, and thus tends to keep the valve in its proper working position and in proper line. The lower part of the rod has a guide and block fitted so that there should be only a direct lift on the rod as distinct from a bending action.



Fig. 77

Momentum Balance piston.—This is a form of balancing arrangement, fitted in some cases where the valves are heavy, and therefore likely to bring a lot of work on the link motion, when the slide valve changes its direction of motion at each end of its strokes.

In fig. 78, a sectional elevation is given of the momentum balance cylinder and piston, which is fitted in a vertical engine immediately above the slide valve. The piston is fitted on the same rod as the valve. The upper end of the cylinder A, may be connected with the exhaust steam pipe, if required. The lower part as will be seen in the sketch is open to the steam side of the slide valve, through an annular space round the rod, provided by having the neck bush made much larger than the rod. A spigot or projecting end is made on the piston, which as the valve comes down gradually fills up this space, and in this way the steam is imprisoned between the piston and the lower end of the cylinder. The imprisoned steam thus forms a cushion and takes the momentum of the valve, bringing it to rest gently and at the same time accumulating sufficient pressure to assist the valve motion in lifting the valve.

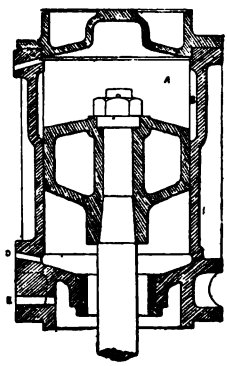


Fig. 78.

On the up stroke the steam is also imprisoned to a certain extent, and a cushion is formed, to prevent this being too great grooves B, are made, so that the pressure may escape into the slide casing below the piston. If the pressure on the upper end of the stroke is less than the steam pressure, this will get through the grooves and assist to bring the motion to rest. Small pipes C and D, are also provided in case of excess of shock, in such a way that by opening a cock on either pipe the pressure can be relieved through the pipe E.

Another system, of balancing the momentum, is by means of Joy's valve and piston arrangement. By ports suitably cut the balance piston is made to perform work, in such a way as to relieve the link motion of all work, except the initial guiding motion.

By the application of the indicator an exact reading of what takes place in the cylinder can be made, and any calculations checked.

Cylindrical or piston slide valve.—This is used very extensively for the high and medium pressure slide valves, in triple and quadruple expansion engines. Fig. 79, shews a section through the valve and cylinder ports. In the figure

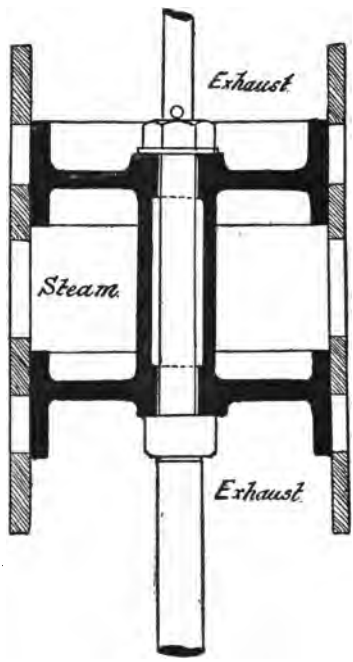


Fig. 79.

steam is admitted from the inner part of the valve, exhaust taking place at the ends. This method has an advantage as it gives more space for exhaust, a shorter valve being sufficient; and the valve rod packing is only subject to exhaust pressure and not to the full pressure. The cylinder ports are generally a separate fitting, as is also the case with the common flat valve.

When this type is used for the low pressure slide valve, packing similar to that used in the engine pistons, is generally fitted to avoid loss from leakage. In the high pressure cylinders a small leakage is in great part compensated by the work being obtained in the next cylinder, and absolute tightness is not so necessary.

Joy's valve gear.—This is an arrangement for working the slide valve without the eccentric motion. Referring to the fig. 80, A B C is the connecting rod, and D E F the valve lever turning about the fulcrum E. One end F of this lever is attached by a link to the slide valve rod, the other end D is

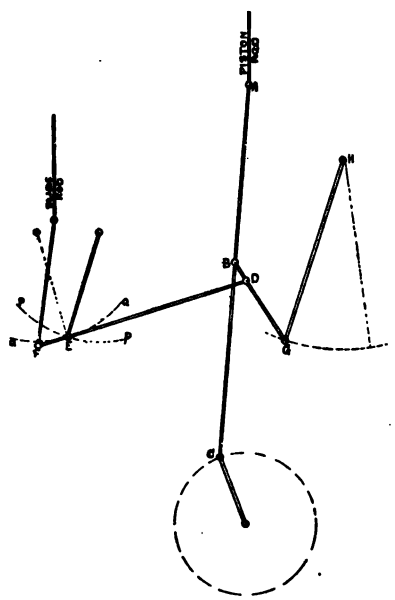


Fig 80.

attached to the connecting rod, by the links B G and G H. The point H is a fixed centre on the engine framing and is the only fixed axis in the gear. The fulcrum E of the lever D E F, is constrained to move in an adjustable path, either moving in a slot, the inclination of which may be altered as in Hackworth's gear, or being suspended, by a link from a movable centre as

in Marshall's gear. Thus the point E may be made to move along the arc PP^1 or the arc QQ^1 at will, and the effect of the change of path is to cause the reversal of the direction of motion of the engines. Intermediate positions correspond to various degrees of linking up. Two independent motions are given to the point F, *First*:—The reciprocations of the piston are transmitted to F by the action of the lever D E F. This portion of F's motion is constant and independent of the position of the gear and the proportions are so chosen that its amount is equal to the *lap* added to the *lead*. In other words the ratio of E F to E D is made equal to the lap+lead, divided by half the stroke of the piston. *Second*:—The vibrations of the connecting rod are communicated to the fulcrum and cause it to move along the curve PP or QQ according to the position of the gear. An additional motion is thus imparted to the valve. This portion of the valve's motion provides for the port opening beyond the amount given by the *lead*, and is made more or less by altering the angle of inclination of the curve. This alteration provides for astern working and for the various grades of *cut off*. If one end of the lever F E D were attached directly to the connecting rod the varying obliquity of this lever would itself cause the fulcrum E to move slightly to and fro on the curve. To avoid this and to secure that the motion of the fulcrum on the curve may be due to the vibrations of the connecting rod only, a parallel motion E D B G H is fitted. This is such that if the point B be moved in a straight line along B C the point E remains stationery. Hence, the disturbing effect of the variation of obliquity of E D is avoided. All points of cut-off, release, compression, etc. obtained by this gear are satisfactory.

For the student it is a simple type of gear to construct for himself, and a working model can be constructed very easily in card board or sheet tin. For teaching the working of the slide valve it is therefore very useful.

Mr. Joy has patented a new gear which is worked by a single eccentric.

The reversing motion is obtained by a hydraulic ram which alters the position of the eccentric on the shaft for astern or ahead motion as required. The mechanism for performing the operation is contained in the shaft. The author has been given to understand that this type of gear has been in successful working on a locomotive engine and that it will be shortly tried for marine work.

Reversing Motion.—In fig. 81 a diagram shews a method known as the continuous motion reversing gear. The gear may be worked either by hand or steam, and the engine need only be capable of going in one direction, but sometimes a differential valve is fitted with a two cylinder engine, so

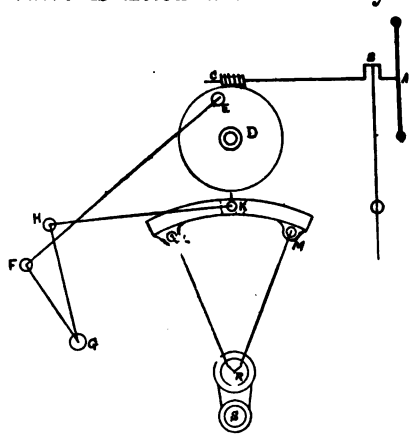


Fig. 81.

that the engine may be reversible. In the figure shewn the shaft A C is revolved either by the wheel A or the reversing engine by the crank B. A pinion C is attached to the shaft working on a worm wheel D, on which a pin E is fixed. A connecting rod E F works an arm F G, keyed to the weigh shaft G. Another arm H G is also keyed to the weigh shaft, with the end H, connected by a rod or rods H K, to the link

L M, at K. R is the centre of the crank shaft, *S* that of the crank pin. R L, R M being the eccentric rods. By following out the motion it is seen that E revolves in a circle, moving F from right to left, or left to right according to the direction of motion of the reversing engine. In this way the links are dragged from right to left or left to right and bring the rod R M or R L in line with the slide rod, and thus give the desired position for either ahead or astern motion of the main engines.

This motion is very quick in its action, and requires very careful balancing of the reciprocating parts of the engine, to prevent the links being run beyond the required position, and therefore not stopping the engine at the exact point required.

This is especially the case with light machinery, and a two cylinder engine, capable of reversing motion, is preferable to one capable of moving in one direction only, and for this reason probably having only one cylinder. With a continuous motion however there is no chance of accident from the starting engine becoming jammed in one position, as sometimes happens when screw gear is fitted. The engine has then to be brought to rest automatically, ahead or astern as required, and any slight derangement of this automatic cut off, results in the link motion being jammed either ahead or astern, and may produce disastrous effects on the ship. With a continuous motion this is impossible, the distance through which the links move being governed by the travel of the pin E cn the worm wheel D.

The continuous motion arrangement is very convenient as the reversing engine can be kept constantly moving slowly when waiting orders or raising steam, and by this means the main engines can be kept uniformly warm and free from water to a great extent. When worked in this manner, the main engines should move about one revolution, as the link gets into the ahead or astern position. This slight motion

frequently produces a slight vacuum in the condenser, (the air pump being also moved with the main engines). A convenient and expeditious means of warming the engines is almost a necessity with water tube boilers, where the time required for raising steam, is, to a great extent, governed by the time required for getting the engines properly warmed.

In fig. 82, *Stevenson's Link* is shewn in a modified form, and is the best known and most used of all methods of reversing. On reference to fig. 81, L M is the link of which the fig. 82, shews the details of the pin connections. By this

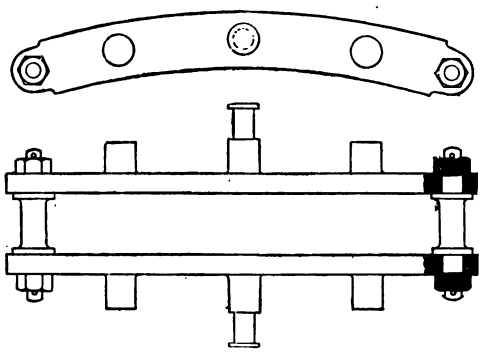


Fig. 82.

method of the double bar, either eccentric rod can be brought into a direct line with the slide rod, through the medium of the *link block* shewn in fig. 83. The link block is attached to the slide

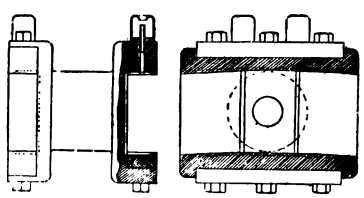


Fig. 83.

rod at its lower end and the link oscillates and slides in it. The working parts of the block are generally lined with gun metal or white metal, and all the pin connections on the link

and weigh shaft are lined in a similar manner. White metal is preferable when steel is used for the links and weigh shaft connections.

The link block is usually made adjustable, when badly adjusted it may cause much trouble from noise or overheating.

A solid bar link is sometimes used, and the link is then *overhung*. The points L and M (fig. 81,) are in this case always outside the line, joining the eccentric centre and the link block.

Effect of "linking up":—This can be shewn by an application of the Zeuner's diagram shewn in fig. 75. Adopting the same nomenclature of points as in that figure, construct the fig. 85, for the valve gear in full gear.

In fig. 84, suppose the link at R, that being the point

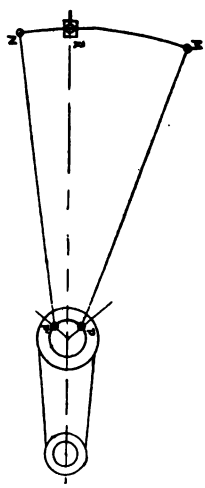


Fig. 84.

at which the link is placed for the required 'linking up.'

In fig. 85, P is the point of 'maximum opening' for *ahead*, and P^1, the similar point for *astern*. Then through $P\ P_1$ draw the arc of a circle with radius =

$$\frac{PM \times PP^1}{2\ MN} \text{ (fig. 84.}$$

Divide this arc at B so that

$$\frac{PB}{PP^1}=\frac{RN}{MN}$$ (fig. 84.

Join AB, and describe a circle on AB as diameter. This will be the valve circle required, and the points of cut-off, release, compression and admission will be as shewn in fig. 85. The maximum opening to steam is CB instead of PD, and all the operations of the valve will be earlier than when in full gear.

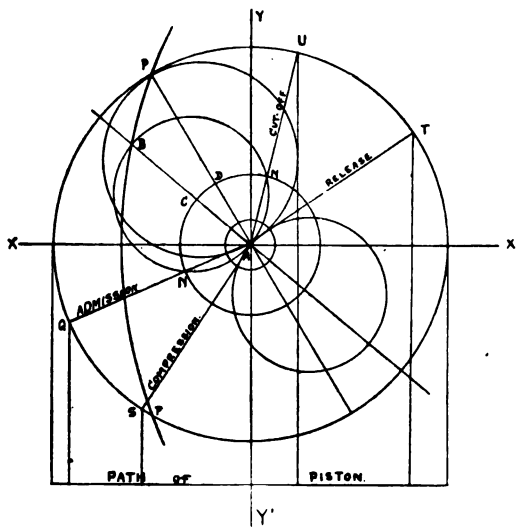


Fig. 85.

In some casss the valve gear is overhung, that is the points M and N are always outside the point R. This is generally the case with the solid bar link. For these cases the point B is outside PP^1 and it is usual to construct the valve circle for a point when R and N are in line and then find the proper position as above for linking up.

If the rods are as in fig. 84, when the crank is turned away the rods are *open*, but if the points MP^1 and NP are joined, and the rods are represented by these lines the rods are '*crossed.*' Open rods are preferable.

CHAPTER XI.

EXPANSION OF STEAM.

THE INDICATOR AND INDICATOR DIAGRAMS.

Expansion.—The principle by which economy is obtained may be shewn from the accompanying fig. 86. Let AD

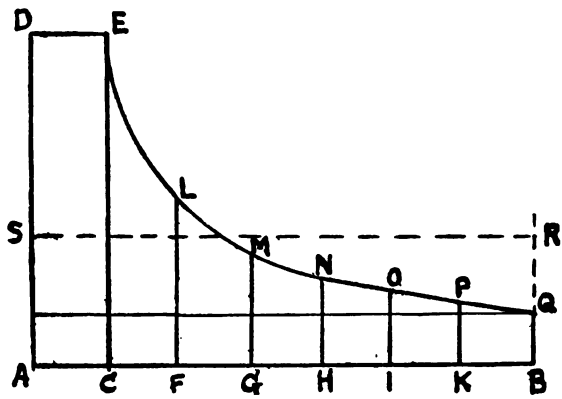


Fig. 86.

represent the steam pressure at the commencement of the stroke of the engine, which is represented by AB; and suppose the steam to act with uniform pressure throughout AC, a fractional part of AB. (That is the cut off by the slide valve will be at C). Take CF, FG, GH, etc., each equal to AC. Through the points C, F, G, etc., draw CE, FL, GM, etc, perpendicular to AB, make CE = AD, FL = $\frac{1}{2}$ AD, GM = $\frac{1}{3}$ AD, and so on. Join DE, and through E, L, M, N, etc., draw a free curve. Then by Marriot's law.—("The pressure of a gas varies inversely as its volume,") the pressure will decrease as the volume or space the gas or steam occupies, increases:—It will follow that if a perpendicular be drawn from any point of

AB to meet the curve, the part intercepted by these two lines, will represent the pressure at the corresponding portion of the stroke; for at F, where the space AF = twice AC, LF has been made equal to half AD. Again, at G, where the space AG is three times AC, we have GM = one third of AD, and so on.

The perpendiculars therefore, at all these points being inversely as the corresponding spaces, it will be the case also at intermediate points, and consequently generally true throughout the curve. Perpendiculars, therefore, from all points from A to C, will represent the pressure of steam before its expansion; and those drawn between C and B, and intersected by the curve, will represent the pressures during expansion. The *sum* of all such lines will therefore represent the whole sum of the pressures during the stroke. These we may suppose the same in amount as the sum of a series of lines, intercepted between the upper dotted line and AB.

Hence the mean pressure during the stroke will be represented by some line RB.

But, since at the *end* of the stroke the pressure of the steam is QB, it follows (the whole cylinder being filled with steam of that pressure) that the quantity of steam, used in one stroke, may be represented by QB. It follows therefore that steam whose quantity is represented by QB, has been enabled by using a greater initial pressure, to perform work represented by RB. This shews the advantage of working expansively for the heat required to obtain a higher pressure is but a very small additional percentage of that required for a lower pressure, while the gain by expansion is a very high one.*

*Considering the figure geometrically, the curve is found to be a *hyperbola* having asymptotes AB. and AD.

Let x = space traversed by the piston to a certain part of the stroke, and Let x = N times AC.

Then if Y = corresponding pressure at this point.

Measurement of the Mean Pressure—Graphically.—An approximate method of obtaining the mean pressure without the aid of the indicator is as follows, fig. 87.

Set up a vertical line AB representing to scale the initial pressure in the cylinder. Produce AB to C, making BC equal to one fourth of AB. From centre C with radius CA draw a segment of a circle cutting BD, which is drawn perpendicular

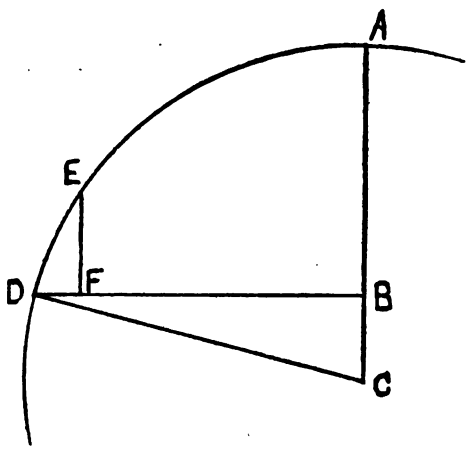


Fig. 87

to AC, at D. Take a point F in BD, such that BF is to FD is the ratio of expansion. (If BD represents the stroke of the piston to scale, then F will represent the point of cut-off approximately.

Draw FE parallel to BA and cutting the circle at E. Then FE will represent the mean pressure to the same scale as BA represents the initial pressure. By subtracting the back pressure the mean *effective* pressure is obtained.

Then $Y=\frac{1}{N}$, EC.

Multiplying, therefore, $X\,Y=N$, $AC\times\frac{1}{N}$, EC.

$=AC\times CE.$

and this is the equation to a hyperbola whose asymptotes are AB. and AD.

Neither this method nor that which may be obtained by means of the figure 86 shewing the expansion curve theoretically are however applicable in actual practice, except in extreme cases. For generally the back or exhaust pressure line will be difficult to obtain graphically, as it is not always horizontal, especially when linked up, so as to produce cushioning, as will be seen from the explanation of the actual diagram expected from an engine.

For actual practice the Indicator is used and has arrived at a very great stage of perfection, and as will be seen it shews in various and distinct ways the working of the engine as well as its defects.

The *indicator* is used to shew by means of a diagram the pressure at any part of the stroke in a steam cylinder, and from this we find much other useful information.

Indicators are generally worked on a similar principle, of which we give an example in fig. 88, *(McInnes Indicator)*. There is a light cylinder of brass or some other metal, round which a paper is stretched. The barrel is moved round on its axis by means of a string, and a spring in tension. The string is actuated or pulled by a system of levers worked from a pin rigidly connected to the piston rod, so that in each stroke of the engine, the barrel is moved round a certain distance by the string and in the return stroke the spring restores the barrel to its original position, and at the end of one revolution the string again pulls the barrel round and so on alternately.

The amount of traverse on the paper in relation to any fixed point bears an exact proportion to the stroke of the piston.



Fig. 88.

Next, there is a piston working in another cylinder, (shewn in section in fig. 88a). The top side of the piston is open to the atmosphere and the under side is in connection with one end of the main steam cylinder. For convenience the piston is generally made a certain area, and is loaded by means of a spring so that when the spring is compressed a certain amount it represents a corresponding pressure per square inch.

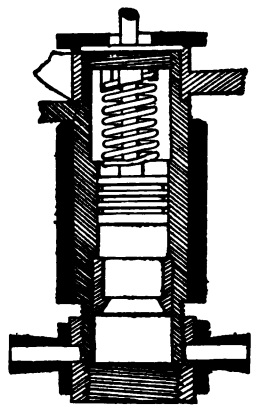


Fig. 88a.

By this means the piston rises or falls in accordance with the pressure in the cylinder. To the top end of the piston rod a pencil is attached, by means of a parallel motion, so that it can press on the paper on the moving barrel. By connecting the string properly we get a figure on the paper, the vertical height of which at any point will represent the pressure at that point of the stroke in lbs. per square inch. The horizontal length will represent one stroke of the engine. That is, the figure gives a graphic representation of the pressure in the cylinder at any point of the stroke.

By an arrangement of the cocks connecting the indicator with the steam cylinder, a similar representation is obtained for the other end of the steam cylinder.

Figure 89 shows a diagram that would be thus obtained in actual practice, and it will be seen that it does not differ very much from what is called the theoretical diagram, shewn in fig. 90.

OA is the line of no pressure or zero.
PB is the line of back pressure.
OF the initial pressure.
FE the steam line.

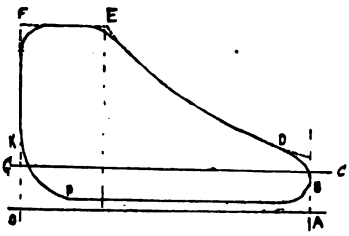


Fig. 89.

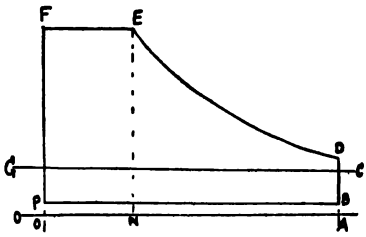


Fig. 90.

ED the expansion line

DA final pressure or exhaust line.

GC the atmospheric line.

In the actual diagram we find that all the points are rounded off, because :—at F the full pressure is not obtained until a little after the begining of the stroke; the *cut-off* is gradual, therefore E is rounded and falls slightly; the expansion line remains much the same until the point D, where exhaust commences, is reached and the pressure continues falling until the end of the stroke; the exhaust is not wide open until after the beginning of the return stroke this gives a rounding of the curve at B. At P the exhaust is closed, and during the remainder of the stroke, the pressure due to compression, rises until the point of admission is reached, when it rises to F and starts another revolution.

All these points affect the working of the engine, generally in a favourable manner, thus the rounding PK prevents shocks in the engine by raising the steam pressure gently and not suddenly, and allows the piston to come to rest without a jar on the rods in altering its direction of motion. This is called the compression or *cushioning corner*. The point D prevents shock in the same way, by preventing a sudden fall of pressure, when the piston is changing its direction. The steam lines and back pressure line should be horizontal, and the admission and exhaust lines vertical if possible, but in the figures next described it will be shewn that they may vary in practice.

The indicator diagrams obtained in practice differ from the diagram expected in various ways, each difference being due to some peculiarity in the construction of the engine or imperfect design. Taking these in detail the first to be considered is that of wire-drawing the steam.

Wire-drawing occurs from insufficient opening of the valve and ports admitting steam to the cylinder, by this means the steam is reduced in pressure before reaching the point of cut-off, the reduction being gradual, so that before the point E is reached the pressure has fallen and has thus produced a gradual rounding of the figure at that point. If this opening is very restricted the steam line FE instead of being horizontal will fall towards E actually reducing the initial pressure just

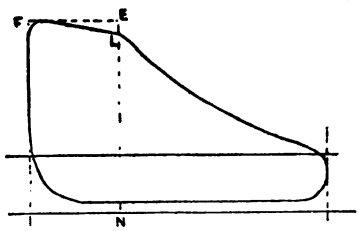


Fig 91.

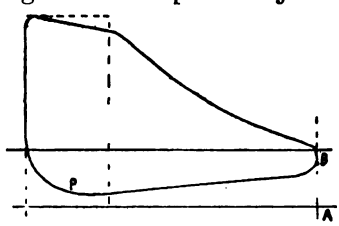


Fig. 92.

before the point of cut-off to NL instead of NE. The wire drawing due to restricted opening to steam is shewn in fig. 91. If the steam and exhaust openings are both contracted the full exhaust pressure is not released at the beginning of the stroke or return stroke, and we get the back pressure line also inclined as shewn in fig. 92, the back pressure line being BP which is not horizontal. This is a serious defect and can only be remedied by enlarging the exhaust ports both in the slide valve and the cylinder. It will be seen that the increase of back pressure continues for nearly the whole of the stroke, and considerably reduces the power of the engine.

Leaky slide valve.—If the slide valve is leaky the steam continues to enter the cylinder after cut-off has taken place and therefore the expansion is not so great, the effect

being to keep the pressure higher. Consequently the expansion curve is higher as shewn in fig. 93 EQB being the expansion curve, instead of EMB.

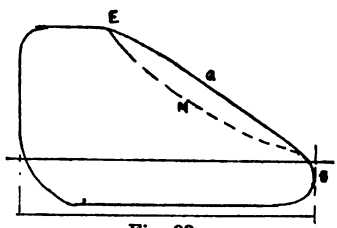


Fig. 93.

A certain amount of steam does not enter the cylinder at all, but leaks into the exhaust side and raises the back pressure. In compound and multi-expansion engines a small percentage of leakage through the high pressure valve is not of very great importance and consequently piston valves are frequently fitted without spring rings. The loss also with very fast running engines is considerably less than with slow moving engines. It is especially important that this loss should not occur in the Low Pressure engine as it would in this case involve a complete loss of the steam that leaked through, and this would possibly increase the back pressure by reducing the vacuum in the condenser.

Leaky Piston.—This defect is shewn by reduction of pressure during expansion and possibly a corresponding rise of back pressure. The steam passes from the steam to the exhaust side of the piston, during the stroke, which increases the back pressure and therefore makes the back pressure line BP, fig. 94, irregular,

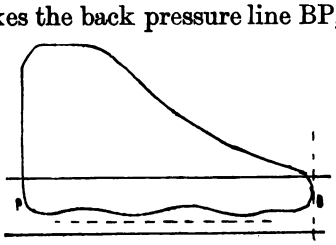


Fig. 94.

and reduces the effective pressure on the piston. If the low piston leaks a certain amount of steam passes to the condenser without doing any work, and thus the total work obtained from the steam is reduced in proportion to the amount of leakage. The effects of leakage are decreased by the employment of compound and multi-expansion engines, but as in the case of the leaky slide valve it is more important that the low pressure pistons do not leak than the high and intermediate pistons.

In fig. 95, some indicator diagrams, are shewn, taken from a low pressure cylinder in which the cylinder liner was worn in such a way that there was a considerable variation of the actual internal diameter, at different parts of the stroke. The piston spring ring was therefore continually expanding and contracting leaving a variable opening at the sliding joint or tongue piece. At this point and also round the greater part of the circumference of the ring leakage was taking place. These diagrams were taken at very low powers and speeds, the initial pressure being 5 to 6 lbs., *absolute* and the pressure in the condenser about 1lb., *absolute*. It appears from the diagrams that so long as the cylinder was open to steam the pressure was maintained, as the leakage was not sufficiently great to overcome the large opening to steam. When cut off took place the leakage quickly equalised the pressures on the opposite sides of the piston and for some portion of the later part of the stroke there was no difference of pressure, the whole having leaked past the piston into the condenser. The opening to the condenser was open nearly the whole of the stroke and consequently the exhaust line in the diagram is almost horizontal throughout. The cushioning

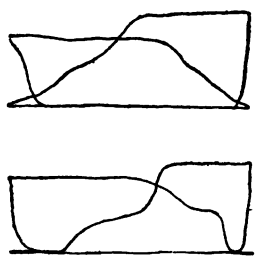


Fig. 95.

corners are peculiar, and very little, if any, cushioning is apparent. It is probable that the leakage was sufficient to overcome any *compression* that should have taken place.

Slide valve incorrectly set on the slide rod.—In this case the slide valve will have too much lap at one end and not sufficient at the other. The valve will therefore admit steam too soon at one end and continue the admission too long, the cut-off being therefore too late and a figure similar

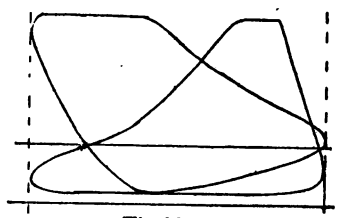


Fig. 96.

to the left-hand one in fig. 96 will be the result. On the exhaust side also, the exhaust will commence late, and the period of exhaust be shortened. Exactly opposite effects are shewn in the diagram at the other end (right hand diagram) *viz.* steam admission late and too short, cut-off too soon, exhaust commencing early and continuing longer.

Angular advance of the eccentric too small.—This will make all the operations of the valve too late and a diagram similar to fig. 97 is the result, the right and left hand

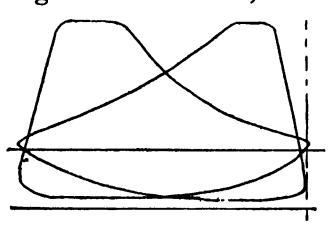


Fig. 97.

figures are however similar in character, the admission lines sloping inwards at the top and both compression corners are small.

Angular advance of the eccentric too great.—In this case all the operations will be too early on both sides, the admission lines sloping outwards at the top and both

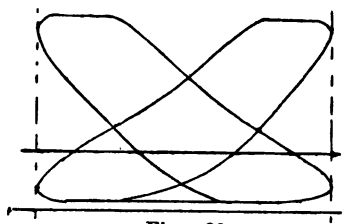


Fig. 98

compression corners being too large. A similar diagram is obtained by *linking up* or "shortening the link," (fig 98).

Friction of the indicator.—Unless the indicator is kept in good order and perfectly clean the piston, pencil and other sliding parts have a tendency to give jerky movements. The

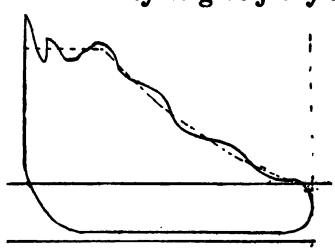


Fig. 99.

friction also decreases the mean pressure obtainable, by raising the back pressure, and by decreasing the height of the initial pressure. (Fig. 99).

Length of the string.—If the string is not properly adjusted for length the barrel of the indicator will come to rest before the piston has reached the end of its stroke, and therefore it is usual to test the adjustment of the string before taking a diagram to see that this does not occur. The effect of a badly adjusted string is evident at once on a diagram by the general appearance of the steam or exhaust lines one of which is vertical with square corners both top and bottom.

It is usual to mark on each diagram, the date and time, with the cylinder from which it is taken, and to record the boiler pressure, receiver pressure and vacuum in condenser, together with the scale of the spring used in the indicator, and also the number of revolutions.

Calculation of indicator diagrams.—The general method adopted for measuring the area of the diagram is to divide it horizontally into ten equal parts, by ten vertical lines as shewn in fig. 100, the two outer spaces forming one part (each being one-half). The mean height is then measured (for

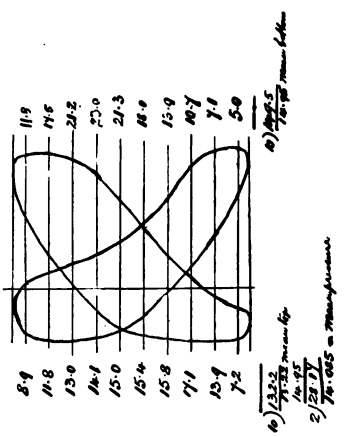


Fig. 100.

each stroke separately) and read off to the proper scale in lbs. per square inch. The mean height is taken to be that contained between the lines of each figure for each stroke. The sum of the heights (or pressures) is then taken and a mean taken of the two means thus obtained. The resultant mean is the mean pressure, during one revolution, in the cylinder. It is generally found convenient to read the results from long scales so as to save the labour of adding. Planimeters are also used but for ordinary purposes of the sea going engineer they are not a necessity although a possible

convenience, the method described above is quite sufficient and by some is considered less liable to error than when taken by a planimeter except in very experienced hands.

Indicated Horse Power.—The mean pressures having been obtained by taking diagrams from each cylinder of the engine and calculating them separately, the indicated horse power is found by taking each cylinder separately and adding together the result as explained below.

Let P = mean effective pressure on the piston in lbs. per square inch.

L = length of stroke of piston in feet.

N = number of revolutions of the engines per minute.

A = area of piston in square inches.

For every revolution of the engine there are two strokes therefore speed of the piston in feet per minute $= 2 \times N \times L$ and, the total pressure on the piston $= P \times A$.

Therefore $2 \times P \times L \times A \times N$ = the number of foot pounds of work developed per minute.

Since, one horse power = 33,000 foot pounds per minute

The *indicated horse power* of the cylinder in question

$$= \frac{2 \times P.\ L.\ A.\ N}{33{,}000}$$

If there be more than one cylinder the horse powers of the several cylinders must be added together, the result being the total horse power indicated by the engine.

Previous to the introduction of the indicator into general use an empirical formula was used, and the *Nominal Horse power* was given by the Admiralty as

$$= \frac{7 \times 2 \times L \times A \times N}{33{,}000.}$$ but various other rules were adopted by makers and they were modified from time to time as pressures increased.

Cylinder constants.– Taking the expressions for the indicated horse power of the cylinder it is seen that the length

of stroke and area of the piston are constant in addition to the figures and consequently the only variables are the mean pressure and number of revolutions.

The invariable part $\frac{2.L.A.}{33000}$ is called the cylinder constant and calculated accurately for each cylinder of the engine, and in this way saves considerable labour in calculation of the indicated horse power.

Clearance.—In every engine the mean pressure is varied by the effect of clearance. The piston cannot be fitted so as to touch the covers at each end of the stroke, and consequently a small amount of space is allowed for safety, should the engine bearings wear, and so alter the exact position of the piston at the ends of the stroke, due to the lengthening or shortening of the rods. The steam passages from the slide valve to the cylinder, and the ports in the slide itself also have to be taken into account. The sum of these several volumes of clearance is ascertained and an equivalent calculated in a fraction of the length of the stroke. The cut off takes place also at a certain fraction of the stroke, and the sum of these fractions actually represents the amount of steam admitted to the cylinder at each stroke. Consequently the expansion line is somewhat higher than in the theoretical diagrams in which clearance has not been allowed for. The effect of clearance is shewn graphically in fig. 101. This affects the rate of expansion for instead of an initial quantity or volume of steam being admitted to the cylinder, equivalent to the cut off, we have an extra quantity due to the clearance, admitted at each stroke.

Thus, let $\frac{1}{r}$ = proportion or fraction of stroke at which steam is cut off.

and let $\frac{1}{c}$ = proportion or fraction of stroke of clearance.

Then, amount of steam admitted at each stroke.

$$= \frac{1}{r} + \frac{1}{c} = \frac{r+c}{rc}$$

At each stroke this quantity of steam is expanded, into the volume of the cylinder struck out by the piston, added to the clearance, that is into a volume represented by, $1 + \frac{1}{c}$

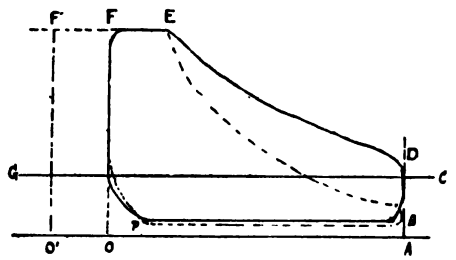


Fig. 101.

Therefore the *actual* rate of expansion is

$$= \frac{1+\frac{1}{c}}{\frac{r+c}{rc}} = r\left(\frac{1+c}{r+c}\right)$$

As an example take a cylinder in which the cut off as shewn by the slide valve (or *apparent* cut off) is at one fourth the stroke, and suppose the clearance is equal to one eighth the volume of the cylinder, then, the *actual* rate of expansion is

$$= 4 \times \frac{1+8}{4+8} = 4 \times \frac{9}{12} = 3$$

So that instead of obtaining four as a ratio of expansion we shall actually only obtain three, the difference being due to the effect of clearance.

The waste of steam resulting from clearance is reduced by the compression at the end of the return stroke. If the compression be so great as to raise the pressure in the clearance spaces, just before the point of admission, to the initial pressure of the steam, loss from clearance is almost a vanishing quantity. At the same time in effecting this saving, a loss of mean

pressure results from the excessive cushioning. In simple engines it is advisable not to run to such an extent as this, but for compound and triple expansion engines when running at low speeds, the economy of steam can be greatly improved, by linking up, (or shortening the link), until a point is reached when the compressing steam, in the high pressure cylinder approaches the initial steam very closely in its pressure, thus producing the highest possible grade of expansion. When the cushion steam exceeds the pressure of the initial steam, it shews itself by a *loop* in the diagram as shewn in fig. 101a. In calculating diagrams with *loops* the area of the loop must be

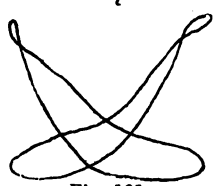


Fig. 101a.

subtracted from the area of the diagram as this represents work done *against* the direction of motion of the piston.

Compounding or *combining diagrams* of compound and other expansion engines is sometimes employed as bearing on the designing of some proportions of engines of a similar type. Having obtained a diagram either in practice, or from calculation, for each cylinder of a triple expansion or other engine, the combining is carried out graphically, as in fig 101, which shews the diagrams combined for a triple expansion engine.

A base line is taken representing to scale the *volume* of the low pressure cylinders, (if there is more than one low pressure cylinder the volumes must be *added* together). Let this length be OB, then mark off OM, representing the volume of the medium pressure cylinder and OH, representing the volume of the high pressure cylinder. Draw a perpendicular OF, representing the absolute pressure of the steam to scale Then with the scale so given mark off the figures from the

actual diagrams taking care that the length and height is on the new scale, and the figures are then found to be somewhat as shewn in the fig. 102. This combined figure is very similar to what might be expected if the steam were cut off at E, and the expansion carried out in a single cylinder. Apparently there

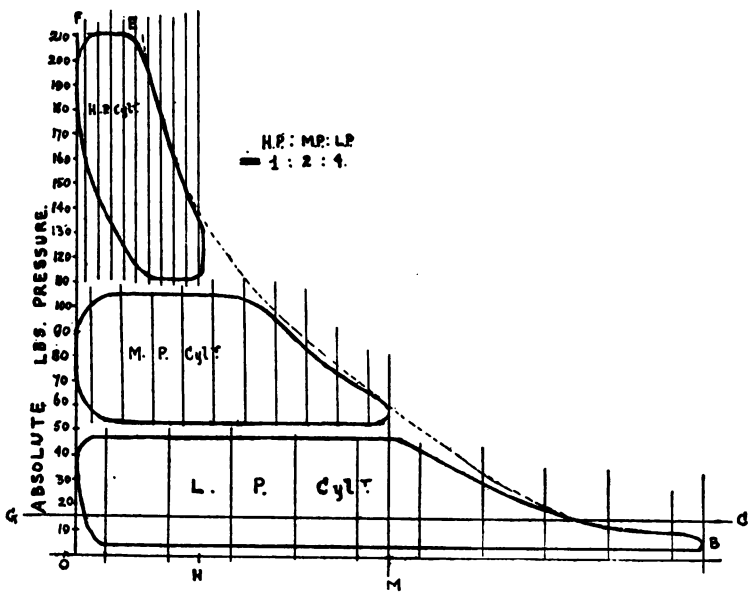


Fig. 102.

is a loss by using three cylinders and compounding the engines, as all the work might be done in a single cylinder of the same volume as the low pressure cylinder. There appears to be a loss between each cylinder and such is actually the case to a slight extent. It is found in practice however that when the expansion is carried out in a single cylinder, that great condensation and other losses take place so that actually the expansion curve would fall below what might be theoretically expected, if these losses were unsuspected.

Much can be learnt by combining diagrams in expansion engines especially when the link is shortened, and in many instances very good results have been obtained by adopting the

linking best suited to each engine. The amount and proportion of clearance can be found in this way, and by a little study and working at a certain rate of expansion, the loss due to clearance can be lessened

CHAPTER XII.

AUXILIARY MACHINERY.

The undermentioned Auxiliary Engines taken from the Italian Ironclad "Re Umberto" serve as a type of those which may generally be found in a large Man-of-War.

Description of Engine used for	No. of Engines fitted.	No. of Cylinders to each engine.	I.H.P. when worked at full power	Total I.H.P., for each descipt.
Hydraulic pumping, Main	2	2	160	320
,, ,, Auxiliary	1	2	80	80
Steering	2	2	100	200
Anchor Capstan	1	2	160	160
Poop Capstan	1	2	40	40
Boat and cargo hoisting	2	2	50	100
Electric lighting	5	2	40	200
Air compressing for Torpedo	2	2	30	60
Fire pumps	2	1	30	60
Circulating pumps	4	1	60	240
Main Feed pumps	4	2	40	160
Auxiliary Feed pumps	6	2	40	240
Bilge pumps	4	2	30	120
Main pumping	1	1	120	120
Boiler room Ventilation	12	1	20	240
General Ventilation	4	1	10	40
Winch hoists, (ammunition and general use)	2	1	25	50
Starting and reversing	2	2	25	50
Auxiliary air pump	1	1	20	20
Distiller circulating	2	1	5	10
Ash hoists	6	1	5	30
Workshop (Engineer's)	1	1	10	10
Fresh water pumps	2	1	2	4
Evaporator feed pumps	2	1	1	2
Oil pumps (liquid fuel)	1	1	1	1
Total	72	104		2557

This list only includes engines worked by steam, but the number of engines is increased by applying the steam engine to storing up energy for other motors worked by hydraulic, electric and pneumatic power. The number of hydraulic engines is sometimes as many as eight, four being for turning the gun platforms, and four for hoisting ammunition from the magazines to the guns. In some cases it has also been used for steering the ship, and for working the capstans and boat hoists.

The electric energy stored is sometimes used also for turning the gun platforms, training the guns and all purposes for which hydraulic power has been used. In the "Re Umberto" the 1500 ampères generated are applied for many purposes beside electric lighting. There are six electric motors for ventilating, four for ammunition hoisting, and six for steering and general purposes. The electro-motive force or pressure used is 65 volts, in the English Navy that generally used is 80 volts.

Compressed air is also used for some of these purposes, but it has not come into very general use, being more or less objectionable, on account of difficulty of storage and being from its expansive power quite as dangerous as steam. The general description and arrangement of hydraulic and electrical machinery may be found in the various manuals issued on the subject, and I do not propose to deal with them in this book.

A consideration, which should always be carefully weighed in the designer's mind or by the advocate of using any power, which must have steam for its prime motor, is, whether the loss of economy and efficiency when using an intermediary such as a hydraulic or electric motor, is outweighed by the general improvement effected by their adoption. Hydraulic, electrical, or any power other than explosive chemicals (powder, gun-cotton, etc.,) must be obtained from the primary motor,

the steam engine, at a loss of economy and efficiency. The efficiency of the steam engine is only about 66°/₀, that of a hydraulic motor about 70°/₀, and of an electric motor 95°/₀ in the best designs. So that in applying hydraulic power under the best conditions the efficiency obtained $= \frac{66}{100} \times \frac{70}{100} = 46.2°/_{0}$ only, compared with a steam engine applied directly. With electricity the efficiency is higher but still there is a loss. The weight of two motors (steam and hydraulic or electric) must also be considered. In some instances, such as training and laying the guns, steam is unsuitable if applied direct, so that other motors are applied and then it is a question of weight principally and the general considerations of utility and repair. For steering the ship steam direct appears most suitable, for if hydraulic power be used it involves an enormous engine continually at work while at sea, and generally wasting a lot of energy, while the steam engine when standing almost still with the helm steady, requires very little steam. An electric steering apparatus involves an accumulator in addition to the dynamo. This is a weighty article and requires good ventilation and space. Improvements are being made daily in the various small matters connected with auxiliary engines, but it appears that their number is rather increasing than decreasing and the space and weight involved adds considerably to the size of the ship. The whole of the engines, as given above, are not in use at the same time but many are frequently used every day, and when steaming at high powers and at general quarters for action, it is evident that the power that can be given to the main engines for propelling the ship is reduced considerably by the power absorbed by the auxiliary machinery.

It is for this reason if for no other that the economy of every auxiliary engine should be increased as much as possible and whenever it is possible to work by hand gear, it should be done. The amount of fuel that can be carried in a vessel is

not great, and as the coal consumption for auxiliary purposes is about *ten tons per diem* in battleships, it becomes a matter of grave responsibility if new mechanical appliances are introduced on any but the most economical basis. As a rough estimate it may be taken that the *radius of action*, (or distance a ship can steam with her own coal supply), is reduced from 10 to 15 per cent, by the auxiliary machinery. In war-time this amount is more likely to be increased than decreased, drills become more frequent, the guns and torpedoes exercised, and, many other small items such as the search lights and steam boats in use nearly every night, all these add to the difficulty.

Some engines are necesary to the propelling machinery and the principal of these are the *feed pumps*, which are generally worked by separate engines. Two sets are fitted, each capable of supplying all the feed necessary, one set being called the main feed, and the other the auxiliary feed pumps. These sets are generally duplicates of each other. The type now most frequently adopted is that without eccentric slide valve motion.

Weir's pump.—The single cylinder type is shewn in fig. 103. The pump rod is a continuation of the piston rod. The slide valve is worked direct from the piston rod. The length of the piston stroke is regulated by the nuts on the valve spindle. The clearance on the top can be ascertained by slacking back the jamb nut on the joint, and screwing up the spindle until the piston touches the cylinder cover; then unscrew for the requisite clearance and screw up the jamb nut. The clearance necessary is about half an inch. Clearance on the bottom is effected by shifting the bottom nuts. The pump buckets have a packing ring cut with a saw but a strong cod piece is fitted and locked to prevent expansion and in this way provision is made for adjustment. Solid buckets are sometimes fitted.

The pump valves are fitted in groups, in each valve box there are a number of small valves. The maximum lift is one quarter of an inch. On the discharge valves there are small

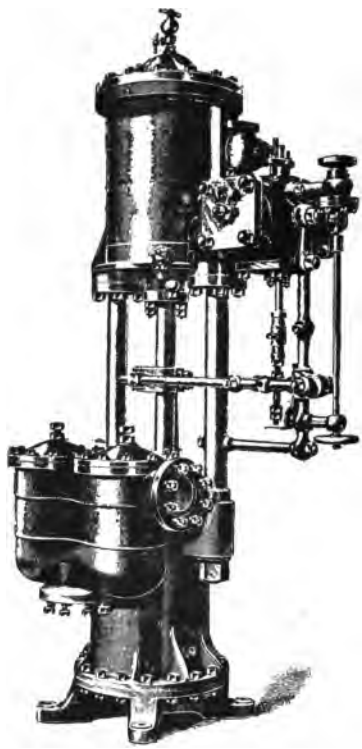


Fig. 103.

spiral springs, the compression being about one eighth of an inch.

The engine is generally controlled by means of a float in the feed tank. The float is attached by levers to the steam

valve so that a constant supply is kept up, proportional to the amount of water used. The arrangement of the float is shewn in fig. 104. An independent steam valve is fitted so that the

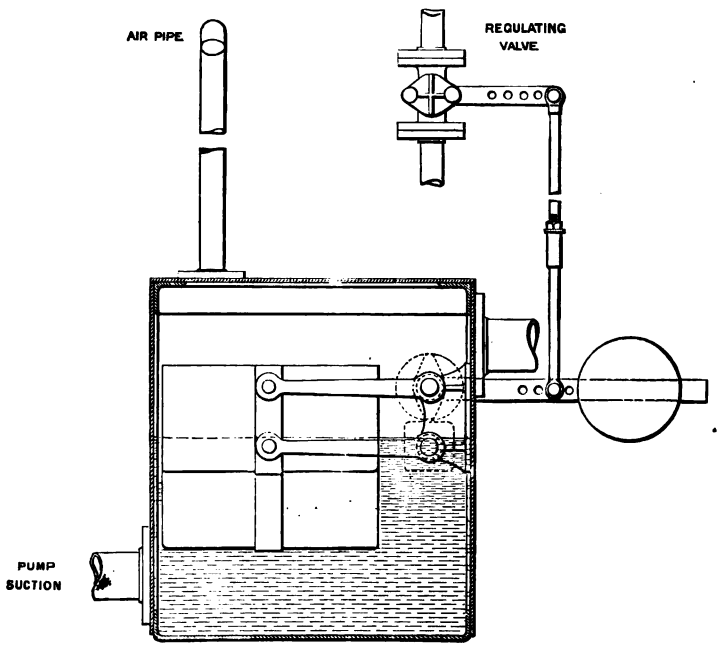


Fig. 104.

float control cannot, by being itself disabled, disable the pump.

For large ships *Weir's Duplex pump* is sometimes fitted. The details of the pumps and valves are similar in arrangement to the single cylinder type. The slide valve is worked by the piston rod of the other cylinder. This arrangement is shewn in fig. 105, and is very similar to that shewn in figs. 106 and 107.

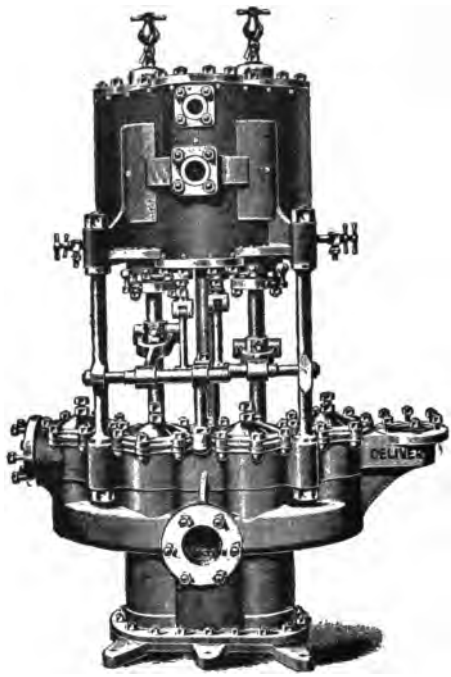


Fig. 105.

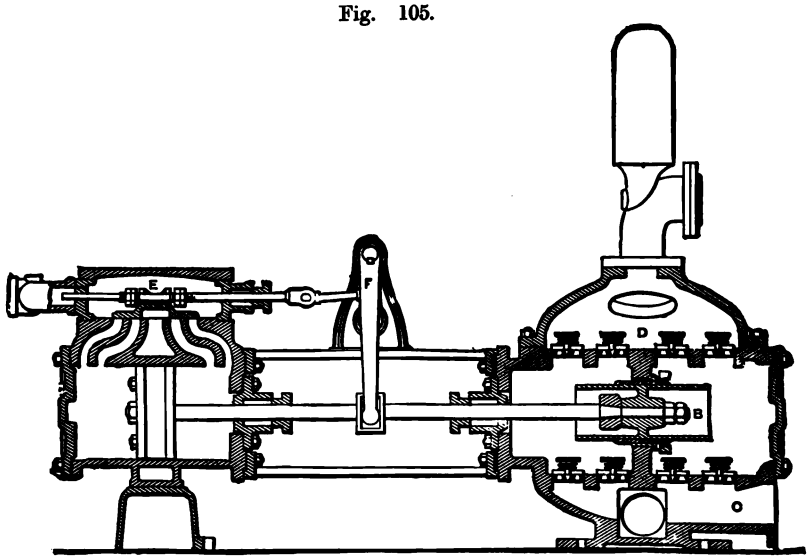


Fig. 106.

The *Worthington steam pump*, as shewn in the sectional view, fig. 106, is of ordinary construction. The valve as shewn at E, is an ordinary slide valve working on a flat face over ports or openings. The motion of the valve is produced by a vibrating arm F, which swings through the whole of the stroke. The moving parts are always in contact. The double acting plunger shewn at B, works through a deep metallic packing ring, bored to an accurate fit, being neither elastic nor adjustable. The sectional view shewn is of a horizontal engine, generally they are made vertical for naval purposes. Separate valve chambers are used for each suction and delivery.

An elevation of two Worthington pumps placed side by side is shewn in fig. 107.

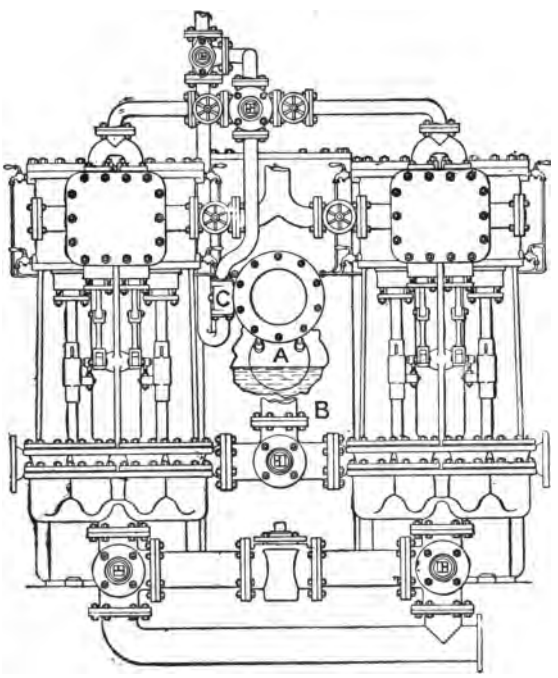


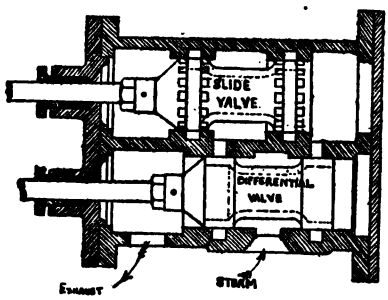
Fig. 107.

It might be mentioned here that no *closed* engines for any purpose are now fitted in the Navy. All auxiliary engines

are of the *open* type, that is, the cranks shafts, connecting rods, and piston rod, and slide rod glands are always accessible when the engines are working. For example, the Brotherhood three cylinder rotatory engine, originally often used for ventilating fans and dynamos, has been superseded by the same maker's *open* engine.

The *fire* and *bilge* pumps are generally separate engines and are similar to the feed pumps in general design. Frequently they are of the same type, the only difference being in the connections and arrangements for suction and delivery.

Differential valve.—A sectional view of this is shewn in fig. 108. It is used for reversing the direction of motion of



Fig, 108.

small engines, where economy is of little consequence and, where link motion would be cumbersome and less quick of action.

The slide valve used with this valve must be *normal*, that is without steam or exhaust lap, and without lead, and consequently the eccentric is set at right angles to the crank. For steering engines, turning engines, starting or reversing engines, and hoisting, capstan and winding engines, two cylinders and two cranks are employed. These engines are usually fitted with differential valves. From the figure it is seen that by moving the differential valve to the right steam is admitted to the right of the slide valve, and the exhaust is open from the middle of the valve. This gives motion to the

engine in one direction. By moving the differential valve to the left the original steam port becomes the exhaust, and the original exhaust port becomes the steam port. This gives the reverse direction of motion of the engine. The usual arrangement for a two cylinder engine is to place the cranks at right angles, and set the eccentrics at right angles to each other, *one* being *opposite* each crank. This arrangement gives a greater certainty of motion when the differential valve is moved.

Steering Engine.—This is generally a two cylinder engine the cranks being set at right angles to each other. The reversing motion is obtained by means of a differential valve.

The diagram shews the manner of obtaining a following motion of the engine corresponding to that of the steering wheel on deck. In fig. 109, A, is the spindle revolved by means of gearing by the steering wheel. If hand gear is

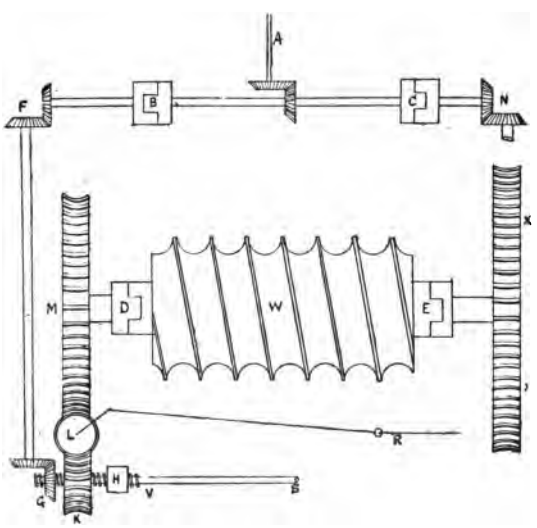


Fig. 109.

required, the clutches B, and D, are thrown out of gear and the clutches C and E, put in gear. Then A, being revolved,

turns N, which by means of a pinion wheel, (not shewn) turns the worm wheel XX, which in its turn revolves the barrel W, on which the chains or ropes for the tiller are rove.

For working by steam the clutches C, and E, are put out of gear and the clutches B, and D, put in gear. Then when A, is revolved it revolves F, and G, in their turn. The spindle VS, is screwed through a bracket H, so that the spindle is moved to the right or left according to the motion of the wheel G. The differential valve is attached to the rod VS, and the slightest movement to the right or left sets the engine in motion, and thus revolves the pinion worm L. This in its turn moves the large worm wheel M, which is attached by the clutch D, to the barrel W. The pinion worm also revolves the worm wheel K, and the direction of motion of the engine is such that K, will revolve the spindle, in the opposite direction to that imparted to it by the steering wheel, so that the spindle VS, always tends to return to a central position and thus bring the engine to rest. The wheel K is free to move to a small extent along the axis of the rod VS. The wheel G, is stationary on the axis, the spindle VS being revolved by means of a long key, sliding in a key way through the wheel G.

The *Davis* patent *spring buffer barrel* is shewn in fig. 110. This is used to prevent shock in connection with the winding arrangement used in the steering gear (shewn in fig. 109,) and in other winding machines.

Some buffer arangement is advisable for the chain connection to the steering gear. The barrel upon which the chain or rope is wound is provided with a central hole, having a square thread of coarse pitch cut in it. The shaft at this part is screwed to suit the hole, so that the barrel is secured loosely to the shaft by spiral feathers. At each end of the

barrel a concentric recess of larger diameter is formed, into which, and around the shaft, a spiral spring is inserted. Provision is made for the lateral movement of the barrel with respect to the shaft. The springs bear against shoulders formed on, or attached to the shaft at each end, which journals upon the collar on the shaft. As soon as the shock or strain is

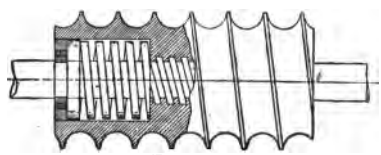


Fig. 110.

exerted on the chain it turns the barrel on the shaft upon the thread, which alters its position laterally to that of the shaft and compresses the spring on one side. Upon the strain being removed the barrel returns to its normal position. This arrangement gives a large range of elastic movement, and consequently a large amount of relief to the strain on the rope or chain.

Reducing Valve.—A section of a reducing valve is shewn in fig. 111. Its use is very general for small engines and auxiliary fittings, where the full pressure of steam is not required or where a constant pressure is necessary to be kept as in an evaporator. With higher pressures in the boilers, it is not always advisable to work at this pressure with capstan, steering and other engines, and here a reducing valve is advisable even if not considered indispensable.

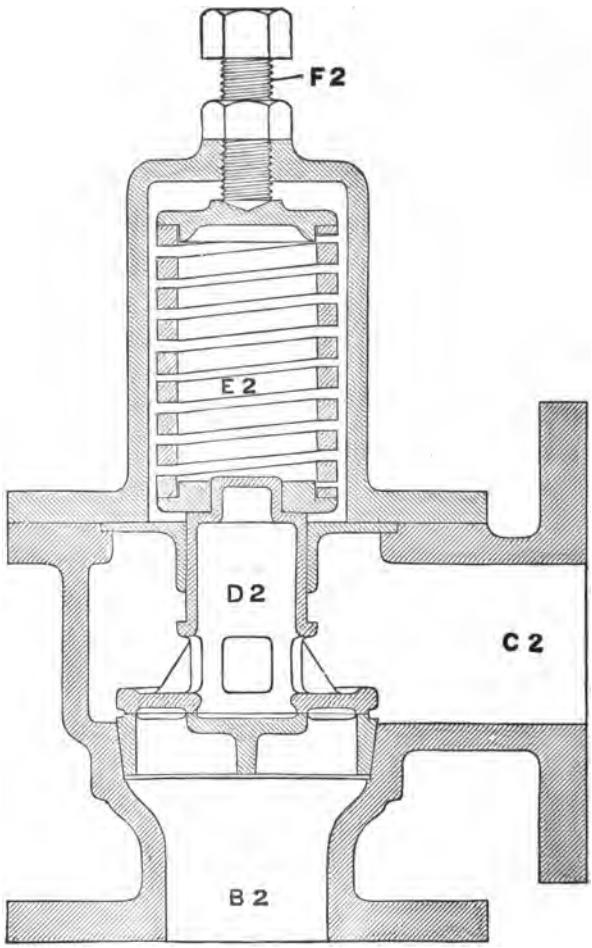


Fig. 111.

The steam enters from the boiler or evaporator at B, lifts the double opening valve D, against the pressure of the spring E, and escapes through C. The spring can be adjusted to any required pressure by the set screw F. It is usually set to maintain a slight pressure in the evaporator. The particular type shewn in fig. 111, is usually fitted to Morison's evaporator.

An auxiliary condenser is now fitted in each engine room of large twin screw ships. They are in all respects similar to the main condensers but are of smaller capacity. Generally the auxiliary air pump and circulating pump are driven by one engine which is made capable of performing the double duty. Arrangement is made so that in the event of a sudden pressure being set up, an escape is open to the atmosphere from the auxiliary exhaust pipe. This valve is called the *atmospheric exhaust* and is really a safety valve set to lift at one or two pounds pressure.

Turning Engine.—Generally small double cylinder engines are fitted for moving the main engines when in harbour and to facilitate adjustments and repairs.

They are connected by means of gearing to the main shafting. A differential valve is generally fitted so that the main engines can be moved in either direction. Hand turning gear is also fitted for all steam vessels. Care must always be taken, that the turning gear is disconnected before steam is admitted to the main engines. Clutches or other suitable arrangements are fitted for disconnecting the turning gear.

NOTE.—The remainder of the Auxiliary machinery not described in this chapter will be found described, where it has been thought necessary to describe them in detail, in other parts of the book.

CHAPTER XIII.

EVAPORATORS, FEED HEATERS AND FILTERS.

THE universal practice on steamships a few years ago was to supply the loss of water due to leakage in a condensing engine from the sea direct to the boilers, but since the introduction of triple expansion, with its higher pressures and temperatures, the necessity for minimising the scale in boilers has resulted in the use of an independent apparatus, in which sea water is evaporated by means of steam, and the generated steam, being condensed, is delivered to the boilers free from all impurities. Apart from the necessity of such an arrangement from an engineering point of view, there is the commercial consideration of reducing the boiler scaling expenses, minimising the liability to accidents, and prolonging the life of the boiler, as, whilst it is possible for careful engineers of long experience to work boilers without an evaporator, there are few superintendents who do not realize the fact that, in order to obtain the greatest engineering and commercial efficiency and as a safeguard against accidents, an evaporator is a necessary auxiliary on board a modern steamship. The quantity of water lost depends on the design and workmanship of the various details subjected to steam pressure, to the number of appliances and arrangements for preventing waste, and to the care of the engineers in charge.

NOTE.—The author is indebted to Mr. D. B. Morison, M.I.M.E. for the calculations of the theoretical heat values and also for the early portion of the chapter. (See Reports, Liverpool Engineering Society, 6th March, 1895. Professor Hele Shaw, M.I.C.E., M.I.M.E., F.R., Met. Soc. President in the Chair.

The chief sources of loss in the main engines are from the piston rod, valve spindle and feed pump glands, but these may be minimised by the use of automatic water drainers and special water saving appliances, examples of which are shown in Fig. 118. Careful attention of those in charge to all the details of the various steam connections is the chief factor, however, as there is no better index of the efficiency of an engine-room staff than in the quantity of auxiliary feed water required.

The ease with which loss of water in marine machinery can be made up, by simply allowing it to flow from the sea to the hot well, has often tended to mislead those in charge as to the quantity which should be required and the quantity actually used. The natural result is that there are a large number of ships in which the loss is most extravagant, the engineers being either unaware of the fact or accepting the condition as normal.

The Committee on Naval Boilers recommend in their report that not less than six tons per 1000 horse-power be allowed, which would be about equivalent to three per cent. of the total feed. This allowance seems very small when the large number of auxiliary engines are considered, but probably the estimate is made on the maximum indicated horse-power which is, of course, very seldom obtained. It is evident, that not only does the amount of *make-up* feed vary for different types of engines, but the variation may be very great in ships of the same class depending entirely on the condition of the main and auxiliary machinery. In passenger ships, where the labour is sufficient to keep everything in good order, a safe allowance is eight tons per 1000 I.H.P. at sea, which, assuming a consumption of 15 lbs. of water per 1 I.H.P. is five per cent. of the total feed; but in cargo ships, where the available labour is much less and so much attention cannot be given to details, 10 tons per 1000 I.H.P. is advisable. In both these cases there is ample room for emergencies, and if

evaporators are fitted of these capacities but still are not sufficient, then the waste of water is highly extravagant and altogether unnecessary.

The amount of make-up feed required in warships varies very considerably, and is proportional to the length of steam and exhaust pipes in use, added to the number of engines in connection with them. The wastage at low powers of large engines (cruising speed) is not very great, and does not increase the harbour loss very considerably.

The *Evaporator* was introduced to the engineering world by Mr. Weir in 1884, and in the form shown in figure 112, in 1887.

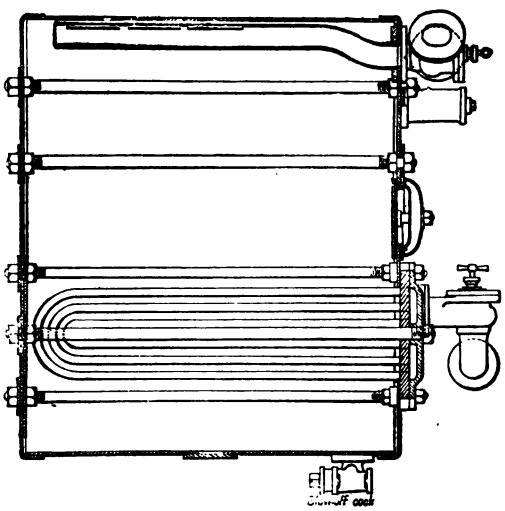


Fig. 112.

Weir's Evaporator.—A sectional elevation of which is shewn in figure 112 and front elevations in figure 119.

It consists of a horizontal cylindrical or elliptical steel shell with two flanged ends, riveted throughout and fitted with the usual mountings which are similar to those on a boiler.

The heating tubes are of U section and are attached to a tube plate, forming part of a hollow door containing the inlet

and outlet chambers. Each tube is flanged at its discharge end, and the diameter of outlet reduced to a minimum in order to maintain the pressure within the tubes and so increase the efficiency of the apparatus.

Sea water is admitted up to the level of the top heating tube Steam is then admitted, and the *generating* steam heats the tubes which in their turn heat the water surrounding them, and finally ebullition takes place. The *gained* steam, that is, the steam generated from the water in the evaporator is taken off by the internal steam pipe and then through the stop valve at the upper part of the front of the evaporator. The *generating* steam may be taken from the boiler direct or from the engine receiver, (M.P. or L.P.) and in some cases is taken from the exhaust to the condenser (supplemented by a small quantity direct from the boiler). The water condensed from the generating steam is taken away by a drain pipe into the condenser or feed tank, or feed heater. It is preferable to have a steam drain trap fitted in the drain pipe for the generating steam. The gained steam may be taken to the condenser direct, or into a feed heater or, as it is sometimes used, as generating steam or *primary* steam for another evaporator as in "double effect" or multiple evaporators. When the evaporator is being used for making water for drinking purposes, the gained steam is taken to a distilling condenser from which it is run through a filter (charcoal or carferal) into the tank or tanks set apart for drinking water.

The same principle dominates all evaporators and it is only the difference of arrangement of the details that constitutes any difference of working.

The capacity of an evaporator is measured by the amount of heating surface it contains. The production varies very considerably, this is due to the rate of conduction. The rate of conduction varies approximately with the difference of temperature of the generating steam and generated steam.

From this it is evident that if a generating pressure of 150 lbs. be employed it will produce double that which could be produced by 50 lbs. of steam. (See table, end of Chapter I.)

The actual amount of heat contained in steam at 150 lbs. pressure is very little greater than that at 50 lbs. pressure.

If the greatest possible amount of water be required in a given time, steam should be employed direct from the boiler at the highest pressure, but if economy is required no worse method can be employed unless the heat carried away in the gained steam is utilised.

Mr. Morison shews this very clearly in his calculations further on.

All evaporators when working should be blown out, and as much scale cracked off as possible, at least twice daily. A pressure of from 7 to 8 lbs., should be maintained in the evaporator, although a considerably higher temperature is required than when working with a vacuum, the total heat of evaporation is very slightly increased (about 2 per cent). The chances of priming are considerably less, as the pressure on the surface of the water prevents the formation of spray which can be carried off by the out going steam. Mr. Weir recommends 10lbs. pressure, and states that the outlet valve should not be opened until a pressure of 15lbs., has been attained, and this is in full accord with the practical experience of sea-going Engineers.

To maintain a regular and constant pressure a reducing valve should be fitted, in conjunction with or in addition to a stop valve, in the outlet pipe of the gained steam.

Rayner's design fig. 113, consists of a vertical cylindrical vessel; the coils are attached to the door as in Weir's, but are in the form of volutes. Two valves controlling the supply to

and from the steam and exhaust chambers in the door are fixed to the body of the evaporating vessel, and connections are made by co-incident ports in the flanges of the door and the vessel,



Fig. 113.

so that when the door is jointed in position these form a continuous passage. The arrangement is very convenient and does not not necessitate the removal of any mountings when withdrawing the tubes. The door and attached tubes are withdrawn from the vessel by a simple overhead runner, the whole forming a very compact apparatus. *Kirkaldy's* latest design is very similar in general detail, the coils being in the form of volutes connected to chambers in the door, the volutes being in pairs arranged in vertical planes, and not horizontal as in Rayner's. Another modification is that manufactured by Messrs. *Maudslay.*

Morison's steel *dome* type *evaporator*, is in the form of a vertical cylinder, the lower part or base having attached to it the spiral coils arranged in pairs. The upper portion is in the form of a dome, which on being raised is supported by standards, thus exposing the coils and enabling them to be readily cleaned.

Morison's radial evaporator, fig. 114, comprises a lower horizontally arranged water vessel, provided with a vertical cylindrical extension forming a steam dome. The lower part of the vessel is fitted with a door which is swung by a pivoted arm, to which it is attached, into such a position as will enable the coils to be withdrawn. The heating coils are arranged in pairs, and are detachably connected to two horizontal tubes,

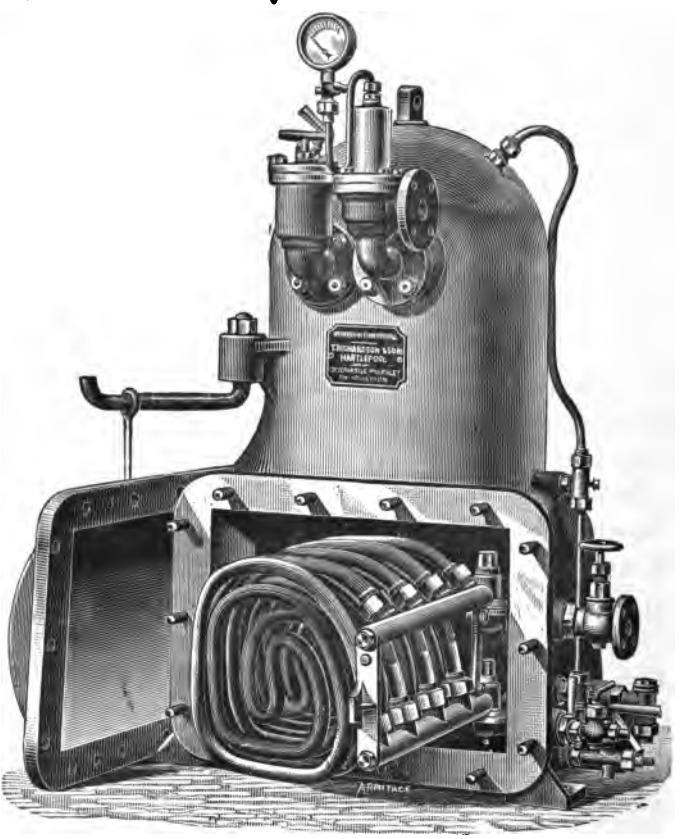


Fig. 114.

forming respectively the inlet for steam and the outlet for the resulting water of condensation. Each of these tubes is closed at its free end, and terminates at its other end in a cap mounted on a hollow plug, so that the tubes and the attached coils can

be readily turned on the hollow plugs as a centre, and so withdrawn from the vessel for cleaning purposes, and afterwards swung back again, these operations being effected without breaking any steam connections. Should it be desired to replace a dirty set of tubes with a clean set, two nuts are removed from the plugs, and the inlet and outlet tubes with all the attached coils are lifted off, and the spare set lifted on. There are no flat-sided steam chests or jointed tube plates in this arrangement, all the parts subjected to boiler pressure being tubular, of brass and copper. Testing is also an easy operation, as by opening the steam valve and closing the drain the entire heating surface can be examined, and all the joints being in front are easily accessible for adjustment. In evaporators of large size the heating surface is divided into two sets, each set being independently mounted on the steam hinges or trunnions; the object of the arrangement being that each set of coils can be lifted by one man without the aid of any mechanical appliance.

An evaporator being simply a boiler, the mountings are very similar. Fig. 115, shows a special *bye-pass drain cock* which admits of continuous brining by an independent adjustment, which is not effected by the complete periodical blowing out of the entire contents.

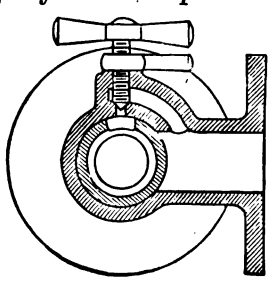


Fig. 115.

In these times of severe competition, when every detail on shipboard is viewed from a commercial standpoint, the probable cost of obtaining fresh water by means of an evaporator is a most important consideration. There are several arrangements available; as steam may be taken from the boiler direct, or from the receiver after having done work in the engine, and the steam generated in the evaporator may either be led to the condenser or to the hot well. In order to

compare the relative economy of these methods, loss by radiation may be neglected as it is practically a constant quantity; also for the sake of simplicity the usual tables on the properties of steam may be taken as applicable to the general conditions.

(1) STEAM SUPPLIED TO THE EVAPORATOR FROM BOILER AND STEAM GENERATED IN EVAPORATOR DISCHARGED TO FEED TANK.

In considering the method by which steam is supplied to the evaporator direct from the boiler, and the steam generated in the evaporator is condensed amongst the feed water in the hot well or its equivalent, let it be assumed that the pressure in the evaporator is one pound per square inch and that the water fed to the evaporator is taken from the circulating pump discharge at a temperature of 80° F. Experience has shown that evaporators at sea should be worked at a density of from $\frac{3}{32}$ to $\frac{4}{32}$, but for purposes of calculation let us assume $\frac{3}{32}$, and in order to maintain that density in the evaporator one-third of the total amount of water fed to the evaporator must be discharged into the bilge or overboard; consequently to produce one pound of pure steam $1\frac{1}{2}$ pounds of sea water must be supplied to the evaporator of which one pound is evaporated into steam and $\frac{1}{2}$ pound is discharged as hot brine, therefore the total heat required to make one pound of pure steam is the sum of the heat in the steam and that in the discharged brine.

The temperature of steam at 16 pounds abs. = 216·3° F,

The heat in one pound of steam at a temperature of 216·3 from water at 80° F. ... ... 1099·4 T.U.

The heat in $\frac{1}{2}$ pound of brine at a temperature of 216·3 from water at 80° F. ... ... 68·1 T.U.

Therefore the total heat required to produce 1 pound of pure steam ... ... 1099·4 + 68·1 = 1167·5 T.U.

As the generated steam is passed direct to the hot well and is entirely condensed amongst the feed water it gives up

the whole of its heat, so the nett cost of producing 1 pound of steam is (1167·5 − 1099·4) = 68·1 T.U., or, in other words, the actual expenditure of heat that is due to brining.

STEAM FROM BOILERS, GENERATED STEAM TO FEED TANK.

Received by evaporator.	Thermal Units.	Discharged by evaporator.	Thermal Units.
Heat required to produce one pound of steam at a temperature of 216·3 above 80	1167·5	Heat given up to Feed water	1099·4
		Balance in brine... ...	68·1
Total ...	1167·5	Total ...	1167·5

The caloric value of 1 pound of good coal may be taken at 14,500 T.U., and by assuming the boiler efficiency to be 66·7 per cent., which was the average result obtained on the trials of the Research Committee of the Institute of Mechanical Engineers, we have $\frac{14{,}500 \times \cdot 666}{966 \cdot 6} = 10$ pounds of water evaporated from and at 212° F., per pound of coal, so that 9666 T.U., will be obtained from the combustion of 1 pound of coal, and the amount of pure steam generated by 1 pound of coal with this arrangement will be $\frac{9666}{68 \cdot 1} = 141 \cdot 9$ pounds, or the amount of coal required to make 1 ton of pure steam $\frac{2240}{141 \cdot 9} = 15 \cdot 7$ pounds.

(2) STEAM SUPPLIED TO EVAPORATOR FROM BOILER AND STEAM GENERATED IN EVAPORATOR DISCHARGED TO CONDENSER.

In this arrangement it is customary to place a vapour or reducing valve between the evaporator and the condenser, the evaporation may be considered to take place at about atmospheric pressure, the feed being at 80° F., as before.

Temperature of steam at atmospheric pressure 212° F.

Heat in 1 pound of steam at 212° F., above water at 80° F., = 1098·1 T.U.

Heat in ½ pound of brine at 212 above water at 80° F., = 66 T.U.

Heat required to produce 1 pound of pure steam
1098·1 + 66 = 1164·1 T.U.

As the steam generated in the evaporator is taken to the condenser and there condensed, it forms 1 pound of pure water at the hot well temperature of 120° F., the total heat above 120° F., carried away in the circulating pump discharge at 80° F., being 1058·1.

Or 1098·1 − 1058·1 = 40 T.U., which represents the amount of useful heat sent to the hot well.

STEAM FROM BOILER, GENERATED STEAM TO CONDENSER,

Received by evaporator.	Thermal Units.	Discharged by evaporator.	Thermal Units.
Heat required to produce 1 pound of steam at a temperature of 212° F. above 80° F.	1164·1	Heat given up by 1 pound of steam in condenser	40·
		Balance of heat lost in circulating water ...	1124·1
Total ...	1164·1	Total ...	1164·1

The net cost of producing 1 pound of steam is, therefore 1124·1 T.U., whilst the combustion of 1 pound of coal would produce $\frac{9666}{1124·1} = 8·6$ pounds, and 1 ton of fresh water would require $\frac{2240}{8·6} = 260$ pounds of coal. These investigations show

that water may be obtained from an evaporator for a nominal expenditure of coal or very wastefully depending entirely on the arrangements adopted. The steam supply from the low-pressure casing is more economical from a heat expenditure point of view than a direct connection to the boiler, but there are practical considerations in favour of the latter which will be referred to later. With reference to the steam generated in the evaporator, there is no doubt whatever that discharging direct to the condenser, although a cheap method as regards the cost of fitting up the apparatus on board, is distinctly the most uneconomical which could be adopted, and although a connection to the condenser is sometimes convenient in port, yet at sea it should never be used, as it is simply equivalent to wilfully throwing coals overboard. There is in the hot well a medium, viz., the feed water, which will readily absorb all the heat contained in the steam generated by the evaporator, and in such a manner that none of the heat so absorbed is wasted; consequently, to adopt any other method is sacrificing possible economy.

The condensing of the steam amongst the feed water naturally raises the temperature of the latter, but not to such a point as will influence the working of the feed pumps unless the design is very faulty. If any difficulty occurs a remedy is often found by making a connection by a $\frac{3}{8}$-inch pipe between the top of the feed pump barrel and the condenser. In order to overcome certain objections to evaporating direct into the hot well, Mr. Morison has adopted an independent vessel, Fig. 116, which has given good results in practice. The vessel contains two chambers, one of which forms a receiver or well for the feed water on its passage from the hot well to the pumps. Projecting into this well is a nozzle with radial openings through which the steam from the evaporator flows, and by giving the water a centrifugal motion is rapidly

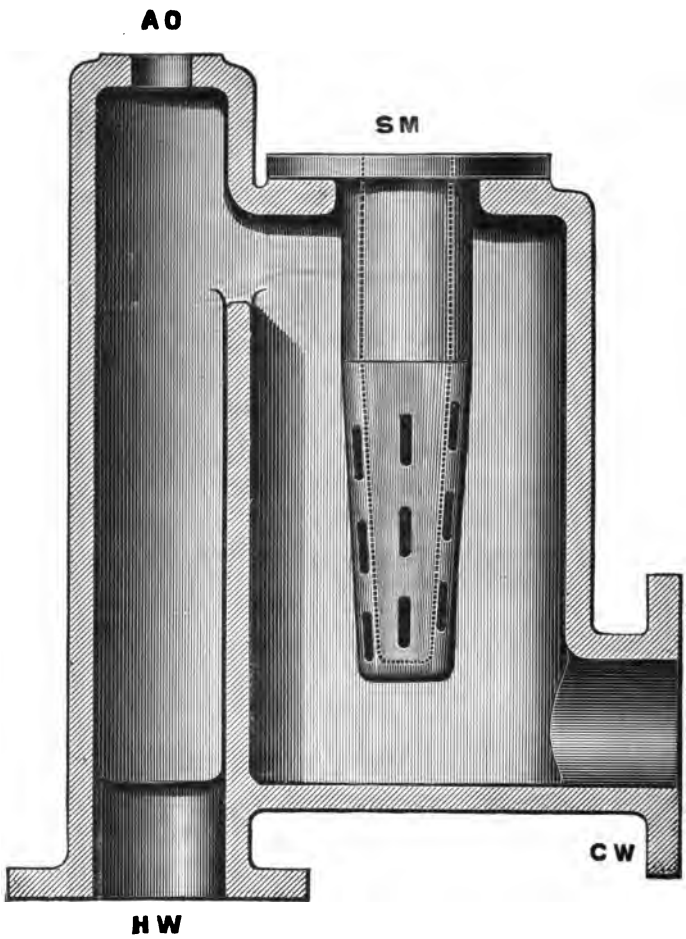


Fig. 116.

condensed; any freed air escapes by an exit pipe, and the heated water overflowing from the receiver is drawn through the suction valve of the feed pump in the usual manner.

Repeated instances have come under notice where the coils have been encased in a solid block of salt or covered with a scale of exceptional hardness. Both these results are due to careless working and insufficient attention to brining. It is necessary for success that the density should be maintained

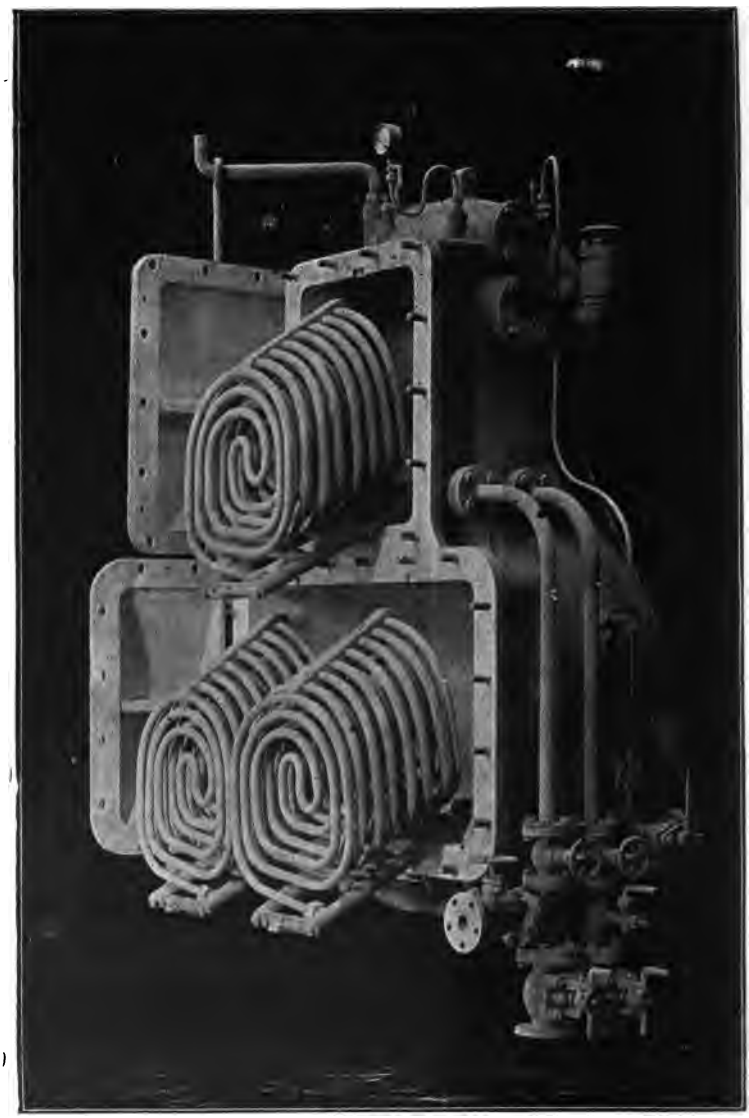


Fig. 117.

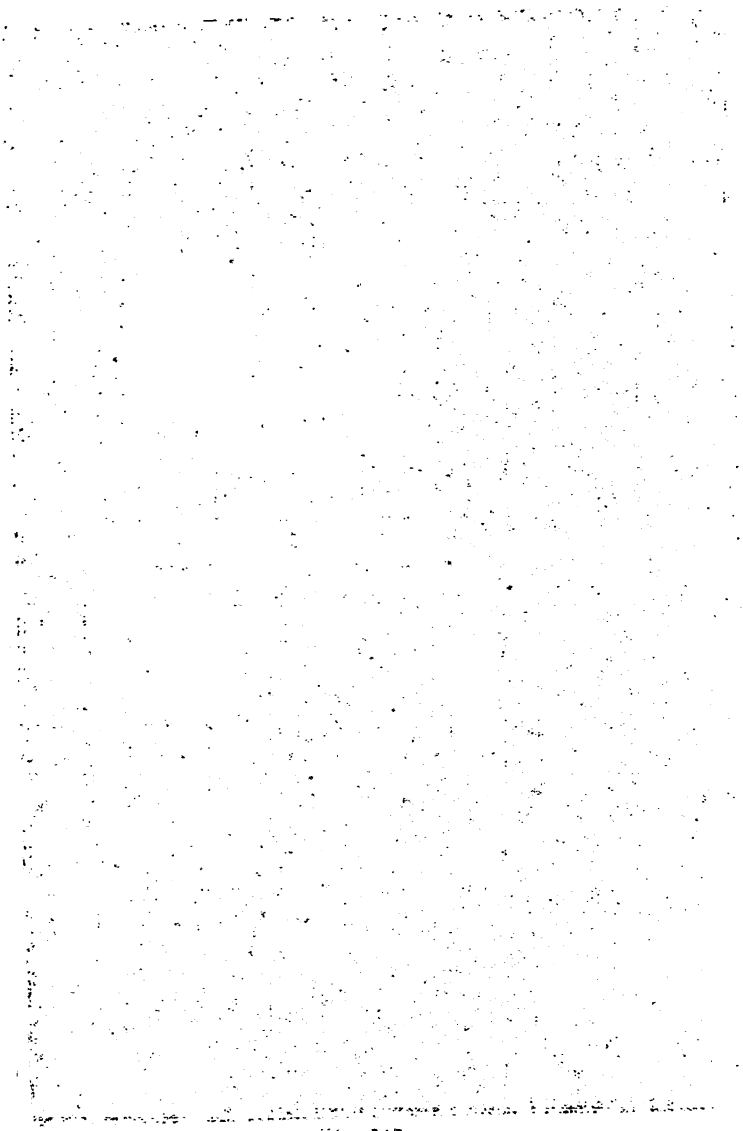


Fig. 117.

from $\frac{3}{32}$ to $\frac{4}{32}$, as if allowed to become too dense, salt will be rapidly deposited on the coils, whilst if the density is kept too low by excessive brining, not only is there a large amount of heat in the discharged water, but the scale formed on the tubes is very hard and difficult to remove. On account of the density of the water and the low pressure of evaporation there is sometimes a slight tendency to prime, and for this reason a portion of the heating surface is usually kept above the water level in order to break up the bubbles and so preventing water, in the form of spray, passing off with the steam.

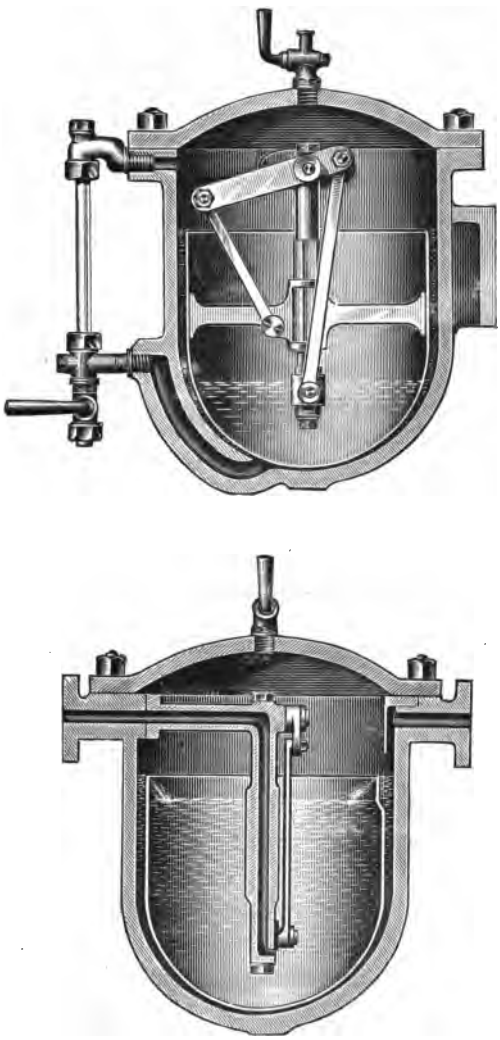
A connection to the condenser is very convenient after blowing down, as the vacuum enables the evaporator to be filled from the sea more rapidly when this is being done. Care should be taken to fully immerse the whole of the tubes before turning on steam, the excess water being drained away as soon as the cracking off process is completed. The detached scale should also be cleaned out frequently, as when present in suspension it increases the tendency to prime.

Evaporators are sometimes used as condensers for winches when in port, and certainly seem well adapted for the purpose. The cooling surface required is usually in excess of what is necessary for evaporating purposes, consequently an increased size of evaporator has to be fitted. In order to minimize this increase in size, Mr. Morison has designed a combined apparatus, as in fig. 117, the feature of which is the utilization of the steam space of an evaporator for the reception of a set of condensing coils, such set being a duplicate of the set of evaporating coils in the lower part of the vessel for which they are available when required. In the illustration the coils are divided into three similar sets. When evaporating, two sets are in use and one set available as spare; when condensing, this spare set is fixed in the steam space so that the available surface when used as a condenser is 33 % greater

than the surface when used as an evaporator. This extra surface in the steam space is also of value when it is desired to work the evaporator at its maximum, as it vaporises any water which may be in the steam due to violent ebullition, and would, therefore be well adapted for warships or torpedo boats where reduction of weight is a great desideratum. On passenger and better class boats, winch condensers or exhaust tanks are a necessity, in order to overcome the delay and inconvenience caused by the escaping steam; but it is the donkey boilers which reap the great benefit, as, in cargo boats especially, they never have a large margin in size, and being fed direct from the sea, thereby causing an ever-increasing accumulation of scale, they constitute not the least of the worries on board a steamship. The question of first cost has been the obstacle, however; but now evaporators are an established necessity, it seems but a natural development that they should, with a little extra outlay, be rendered available for condensing purposes and so materially add to the general efficiency.

One of the most useful appliances in an engine room and wherever steam is employed is the *steam drain trap*. Geddes' type of this fitting is shown in figure 118, which gives two sectional elevations. The action is of a simple nature, the drain pipe is connected to the drain trap, and as the water accumulates *around* the inner basin or vessel it gradually fills the inner vessel, which sinks, until by means of levers a small hole is opened through which the water can escape to a pipe. A water gauge is provided so that the height of the water can be seen. The cock on the top can be used to try the apparatus and also to release any air that may accumulate.

For draining steam pipes, packing glands of large engines, cylinder jackets, evaporators and many other parts of the machinery, the steam drain trap plays a useful part as

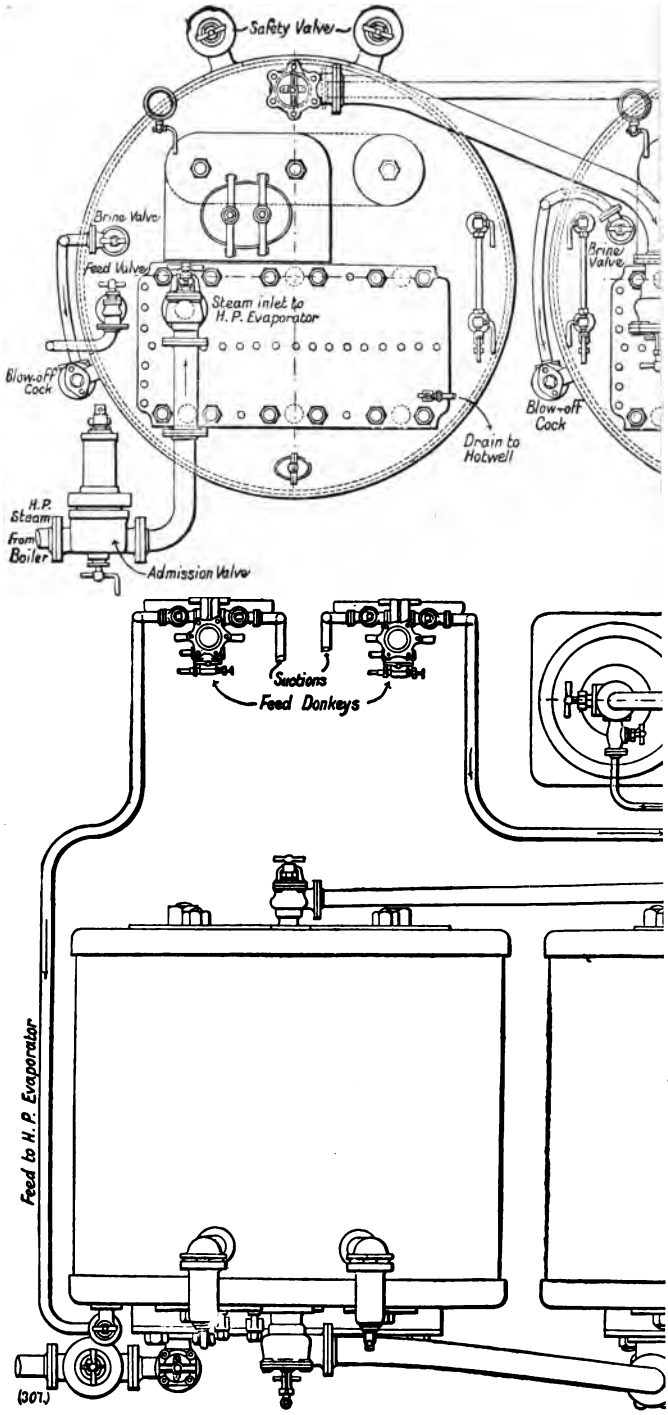


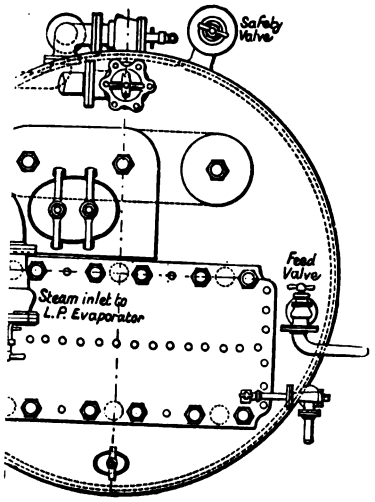
Figs. 118.

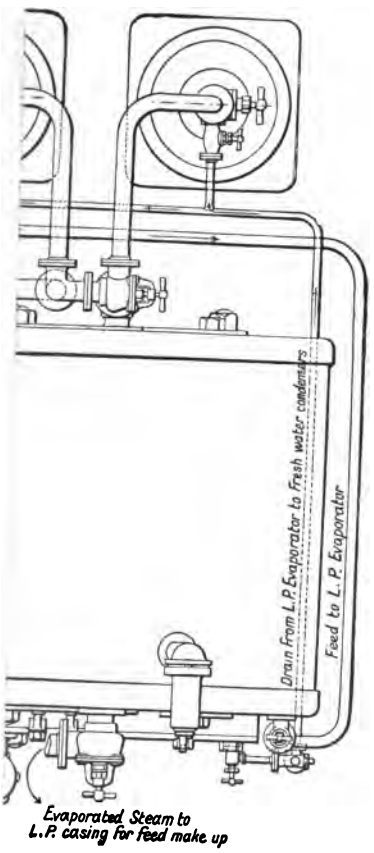
well as an economiser of all losses of heat. Every evaporator should have a drain trap fitted to the drain from the coils, so that steam cannot pass away with the drain water. In this manner only can the greatest quantity of heat be extracted from the generating steam.

An arrangement is shewn in figure 119 of two Weir's evaporators fitted for working *compound* or "*double effect.*" These produce good results and where as in warships water from the land is not very reliable for drinking and sanitary purposes, and consequently a constant supply has to be maintained even in harbour, it is a comparatively economical method. Where two or more evaporators are fitted the *generated* steam from one is used as the *generating* steam for the second, and so on. The drain water from the generating coils in the first is led to the hot well, feed tank, or condenser, and that from the second is led through and cooled down in the fresh water condenser if required for drinking water. This method compares favourably, in its results, with the simple method of distilling direct from the boiler. It appears to be particularly suitable to warships where evaporating is carried on chiefly when the main engines are not moving, and the product is stored in reserve tanks.

In the *Worthington Feed Water Heater* shewn in figure 120, the exhaust steam from the auxiliary engines, or other part of the engines, enters the pipe A, through valve B, into the annular space and through the perforated plate into the heater. The feed water from the hot well is forced by a pump through the pipe C to the valve D, and is sprayed throughout the upper part of the Chamber, the valve being loaded to open at any desired pressure by means of a spring adjustable by the central spindle. As the water collects in the bottom of the heater it lifts the float E, which opens the valve F and admits steam through the pipe G to the second pump, which forces the heated water into the boiler. The valve F is so arranged that there is no external gland requiring packing, which if improperly adjusted would cause the valve to stick, or cause a leakage of steam into the engine room. The float E and the head H can be removed without in any way disturbing the valve F, or the pipe connections. A small


Safety Valve
Brine Valve
Feed Valve
Steam inlet to H. P. Evaporator
Blow-off Cock
Drain to Hotwell
Brine Valve
Blow-off Cock
H.P. Steam From Boiler
Admission Valve
Suctions
Feed Donkeys
Feed to H. P. Evaporator
(307.)


Safety Valve
Feed Valve
Steam inlet to L.P. Evaporator


Drain from L.P. Evaporator to Fresh water condensers
Feed to L.P. Evaporator
Evaporated Steam to L.P. casing for feed make up

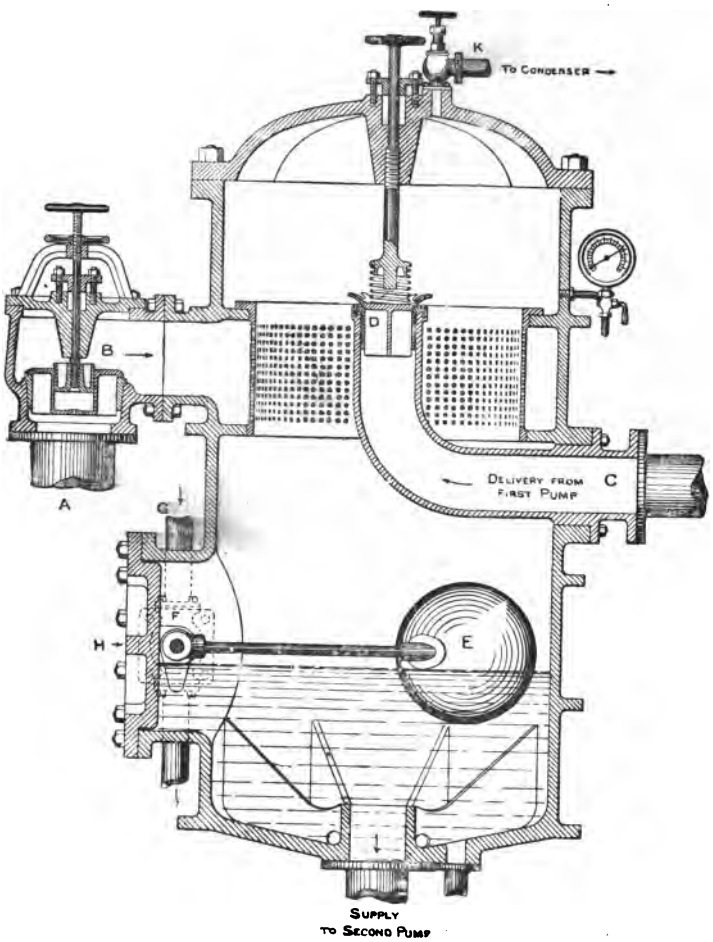


Fig. 120

valve K connects the top of the heater with the condenser, so that any air or condensed vapour collected in the top of the heater is at once drawn into the condenser. The valve can be set open to any extent that may be desired. Safety valves are also fitted to prevent accumulations of pressure.

In the consideration of the working and economy of evaporators, the *feed heater* takes an important place as the

economiser. It is also fitted as an independent feature or element, M. Normand claims from experiments made with and without his apparatus, on board certain torpedo boats, that a gain in the economy of coal of nearly twenty per cent. was made by the use of the feed heater. In the *Normand feed heater* steam is taken from the low pressure receiver after it has done two thirds of its work. Calculated adiabatically a better result is possible although it appears very remarkable. Since 1892 the efficiency of the Normand feed heater has been increased by the introduction of a series of baffles or deflectors and in this way the temperature of the feed water has been raised to within 4° to 15° of that of the heating steam.

With heaters of this type generally known as *surface heaters* there is practically no limit to the temperature of delivery of feed water into the boiler except that of the heating steam.

There is no economy in a feed heater for which *boiler steam* is used. This is evident if it be considered that the steam from the boiler cannot impart a greater quantity of heat to the water than has been given to it in the boiler, and that however efficient the heater may be there must be some loss through radiation and other causes. Economy however can be gained by using *exhaust steam* for this purpose and in this manner saving some of the heat in the steam which has already done its work.

Economy can also be gained by using the exhaust steam from the M.P or H.P. cylinder after it has done two thirds or one third of its work.

The heat dissipated in the condenser is an enormous loss of efficiency and work, and therefore great economy may be gained by transforming this heat into useful work.

In addition to increasing the economy of the fuel, the feed water heater appears to be conducive to the preservation of the life of the boiler, by decreasing the range of temperature in the boiler. With boilers of high pressures, 200lbs., for example, which has an equivalent temperature of 397° the range of temperature is,

(1) without feed heater, $397-100=297°$
(2) with surface feed heater, $397-250=147°$
(3) with jet feed heater, $397-180=217°$.

In example (2) the feed heater is placed between the feed pump and the boiler, as in the Normand, Weir and other similar types. In example (3), the feed heater is placed on the suction side of the feed pump as in figs. 116, 120, and other similar types.

To heat the feed water so high as 250° is thought by some engineers to be excessive, but there is no objection to it if proper means are taken to relieve it of any vapour, and the pressure is kept above that necessary for the equivalent evaporation. Generally 180° to 190° is the maximum temperature used.

Distilling Condenser.—This is used for producing pure fresh water for drinking and sanitary purposes. A complete apparatus comprising evaporator, distilling condenser and pump as fitted by Messrs. Caird and Rayner, is shewn in fig. 121. The evaporator is similar to that shewn in fig. 113. The distilling condenser into which the steam passes from the evaporator is on the right. The interior has a set of tubular spiral coils fitted and made of copper. The steam passes from the evaporator to the interior of the coils and is condensed by sea water cirulated on the outside of the coils. The automatic feed for the evaporator takes its supply from the circulating water so that it is warmed to a slight extent before finding its way into the evaporator. The engine drives three pumps,

that on the right, pumps the brine water overboard. The centre pump takes its supply from the sea and provides the circulating water for the distiller and at the same time feeds the evaporator. A pressure is maintained on the cooling side of the distiller sufficient for this purpose. The third pump that on the left, takes away the condensed fresh water from the distiller and pumps it to the ship's tanks or as required. This arrangement can be fitted up in a very small space. The

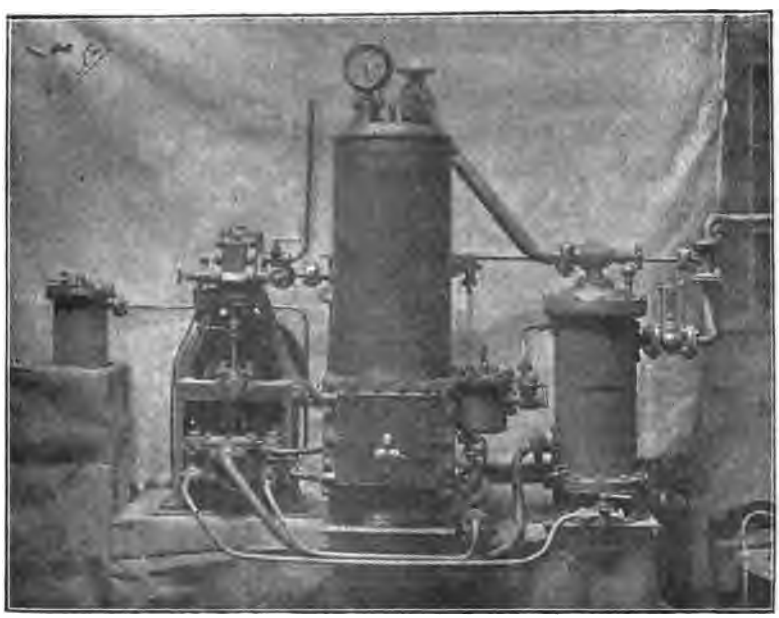


Fig. 121.

whole of the vapour given off by the evaporator is not required to be condensed for drinking, part being used for making up boiler feed loss, and consequently the output of the distiller can be made much smaller than that of the evaporator. In some torpedo boat destroyers for an example the output (maximum) of the evaporator is about 12 tons per diem but of

this only two tons can be condensed for drinking purposes. A greater quantity may be passed through the distiller but it will be warm water and not cold.

The amount of water required in a warship, for drinking cooking and sanitary purposes is about one ton for every 50 to 75 persons on board. When distilling direct from a boiler from 6 to 7 tons of water were produced from 1 ton of coal, but with an evaporator distilling direct into a condenser only 4 to 5 tons are produced per 1 ton of coal. This loss is great but it is covered by increased efficiency of the boilers, and thus keeping under steam for protracted periods is a possibility with all boilers constantly in use. The gained steam or water when required for drinking cannot be used as a jet injection for heating the feed water, but it may by suitable means be used as a surface feed heater, or it may be turned back into the heating coils of the evaporator, and only the drain water used, and taken to the distilling condenser. This latter method may have been objectionable a few years ago, as the amount of heat required in the coils had to be, and still is, supplemented by steam direct from the boiler, and consequently might produce water of a greasy nature. Now, as boilers are generally free from grease deposits, and are fed almost entirely with clean water, there is no reason why the waste heat should not be utilised in this way, and a considerable saving of coal effected.

Weir's "double effect" arrangement has increased the production per ton of coal and as pressures in boilers are increased "triple and other multiple effects" will no doubt come into general use when cold water is required and where economy cannot be obtained by feed heating.

Edmiston Filter.—(Fig. 122.) This is used for cleaning the feed water, and is usually placed between the pumps and heater or between the pumps and boilers, if no heater is fitted. The principal feature is that the water is passed through three successive layers of filtering cloth, by which the finest oil is

extracted. When the cloths become foul, the resistance is shown by the pressure gauge. By blowing *low pressure* steam, with a little soda, into the filtering chamber, which is left two thirds full of water, the grease and sediment is boiled out of the cloths and the whole discharged by the sludge cock.

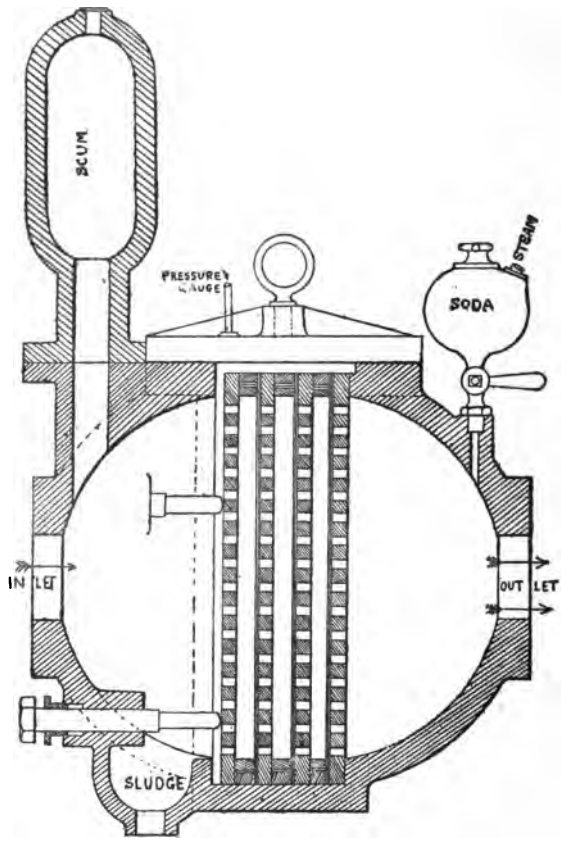


Fig. 122.

The cleaning can be done in two or three minutes, and when completed it is found that the resistance is down to the original figure at which it was started when the cloths were clean, usually about 5 lbs., above the working pressure. The air vessel (marked *scum* in the figure) is used as a receiver for

light oily water which can be passed off by means of a pet cock on the top. The cloths are stretched upon split rings, so that they can be quickly fitted by hammering down the larger ring on top of the smaller one. The cloths are then put in place each set being supported by a perforated plate. Another perforated plate is placed in front and then the whole jointed together, as shewn in the figure, by bolts screwed through the outer casing from the outside. The cover is then jointed up and by opening the inlet and outlet valves, the filter is again in use. A bye-pass pipe is usually fitted, so that the feed water can be passed through it when the filter is not in operation. This filter is a most useful fitting and its simplicity together with its accessibility, adds to its usefulness and popularity with Engineers.

CHAPTER XIV.

CARE AND MANAGEMENT OF THE MACHINERY.

Care and management of Machinery.—If the full pressure of steam be admitted to the cylinders or steam pipes, before they are thoroughly warmed, there is great danger of their cracking or bursting from unequal expansion. The engines should therefore be warmed gradually, and when possible the hot air and steam should be allowed to pass into the steam pipes and engines, as soon as fires are lighted. The jacket steam should always be used for warming engines and the jackets drained occasionally. The cylinder and slide casing drains should be kept open, until steam begins to be emitted from the drain pipes into the bilge, and then opened occasionally afterwards. If the drain pipes lead into the condenser, they may be left open until after the ship is underweigh.

The engines should always be drained, after being stopped for even only a few minutes, so as to get rid of any accumulation of water. When opening steam to any pipe or engine, care should be taken to open very slowly at first until the pipe or engine is warm, and for this purpose, to promote a movement or circulation of the steam, it is advisable to open any drain cocks that may be fitted on the part to which steam is being admitted. More accidents happen from the neglect of proper precautions in warming engines and pipes, than from any other cause. Exhaust valves are fitted to most of the Auxiliary Engines, and these should be seen properly open before putting steam on.

Imperfect alignment is a fruitful cause of heated bearings and in making adjustments, especially of connecting rod bearings, the rod should be *swung* before connecting up, tc see that the lateral play is about equal, each end being taken in turn. With the main bearings it is more difficult, but by screwing up two or more bearings fairly tightly, and then testing with the callipers the shafting near the bearing to be adjusted, a very approximate measurement of any mal-alignment can be obtained. Lead wire is sometimes used for taking adjustments of bearings, but it is not a very reliable method. It is preferable to see that the nuts run easily on the bolts up to and past the usual position of the nut, and then to screw up *without* the liners in place until quite tight. The nut is then slacked back, a certain amount, varying from $\frac{1}{50}$th., to $\frac{1}{100}$th., of an inch along the bolt. The screwing up should be done by one hand using a short spanner with a steady pull and without jerking. After slacking back, a chisel or pinch bar should be inserted beside the connecting rod, so as to try the sideplay, and if the rod moves fairly easily it will be found a good adjustment. The side movement cannot be tried in some bearings, such as the main bearings, but very little experience will tell the requisite amount of slacking required. To test the amount of *slack* use a little piece of soft white lead about the size of a good sized gun shot, and screw up the bearing on the white lead until the proposed point of adjustment is reached; the thickness of the white lead will then verify the amount of slack. Whatever the method, wherever possible, the adjustment should be tested by the pinch-bar. The amount of slack is generally expressed by the amount of movement of a particular corner of each nut. When complete the liners should be tightly held by the bolts so as to prevent any hammering on the liners. A slack bearing means *hammering* in some form or other and frequently results in broken pistons or cracked brasses.

Horizontal engine pistons should be carefully watched, and kept lined up to the central position. The packing rings should be left free to move between the piston and the junk-ring, so as to allow the springs to press the packing ring out in the manner designed. If the packing ring becomes stuck either a leak from one side of the piston to the other takes place, or the strain on the engine is considerably increased. The packing ring should always be maintained as a "*floating ring.*" When lining up pistons it is usual to set them slightly above the central position, so as to allow for wearing down. This amount is from $\frac{1}{64}$th, to $\frac{1}{32}$nd, of an inch and should not be greater.

The crank, and tunnel or after shafting, should be kept in line, this is easily tested by disconnecting the couplings, and if requisite lining up the shafting. Imperfect alignment puts a great strain on the coupling bolts, producing a bending action of the shaft at every revolution; the extra friction is great and this sometimes causes a break down.

The *thrust collars* should be carefully adjusted so that they each take an equal share of the work and take it evenly. The *outside* water circulation should be generally used, this tends to preserve an equable temperature of the whole block and part of shaft within the block. If the water is taken *inside*, or directly on to the shaft inside the block it should be used as sparingly as possible, and always shut off for sometime before the engines are finished with.

The *air pump* should be an easy working fit in the barrel, especially in fast running engines. The air pump valves should be kept free from grease, and if the bucket is fitted with metallic valves they require to be properly bedded on their seatings.

The *condenser* should be kept thoroughly clean, and when any soda or potash is used for cleaning, it should be kept as much as possible from entering the boilers. Few things are

more difficult to maintain or easier to loose than a good vacuum, it therefore is an important matter to keep the air pump, condenser, and exhaust connections, in good working condition and no opportunity should be lost of their being examined and made as efficient as possible.

Internal lubrication can be abused to a great extent and an excess used of mineral oil. In modern practice it is not generally required at all either in vertical or horizontal engines, and in older designs it may be considerably decreased by strict attention to details of working. The principal cause for requiring lubrication is an excessive pressure in the cylinder and slide jackets, thus preventing any liquefaction of the steam as it does its work. Instead of oil this water of liquefaction can be made to perform the same duty in reducing the friction by judicious management. This is especially the case with high pressures and high rates of expansion. To reduce the friction the packing rings in the pistons should be narrow, not more than one inch in width, and where broader rings are fitted, grooves should be cut with a file circumferentially to hold the water of liquefaction, the grooves need not be large, only wide enough and deep enough to lay a fine needle or pin in them, and they should be placed at intervals of from $\frac{1}{2}''$ to $1''$ apart. The faces of the slide valve can be roughed in a similar manner, the cutting or grooving should be at right angles to the direction of motion. This grooving should not be done in such a way as to interfere with the *trueness* of the surfaces. The piston and slide rods require a very little lubrication if properly packed, and with some of the best white metal floating packings, oil lubrication has been entirely dispensed with; a little fresh water put on with a syringe is generally sufficient with metallic packing, where the adjustment is good. The use of water on bearings should be kept as low as possible. Many bearings run a little warm, and remain at from 30° to 40° above the ordinary temperature of the

engine room and although a little water is occasionally required it is perhaps better as a precaution to have a slight drip on the *outside* of the bearing to keep this temperature within reasonable limits.

All bearings, on which water have been used, should be opened out and cleaned as soon as possible after arrival in harbour. Although the engines may be turned by hand daily, the surfaces especially when steel and gun metal are in contact soon become rough, and corrosion goes on after a short time.

For *external* lubrication the *syphon worsted* stands far above any other mechanical appliance, it is simple and certain in its action when kept in good working order. Shut off cocks are also very useful when fitted at the lower end of the syphon pipe. A sectional elevation of this arrangement is shewn in fig. 123.

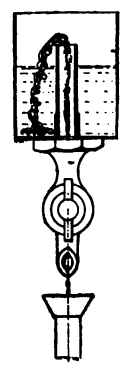


Fig. 123.

Linking up.—Full advantage should be taken of using the link at all powers, and also the separate links very frequently fitted to each link motion. If the engine is linked up by means of the main link, an earlier cut off is obtained in the high pressure cylinder, and therefore a higher rate of expansion, but the ratio of powers in the cylinders will tend to become a little unequal. With a well adjusted engine this slight difference is immaterial, and the gain in economy by using a higher rate of expansion is considerable. The separate links can be used for equalising the work in the cylinders, and where diagrams are frequently taken the proper setting of the links can soon be obtained for a given number of revolutions. With boilers with small steam space it is advisable to work at higher pressures than otherwise necessary, thus obtaining in reserve

a greater quantity of steam. Generally the boiler pressure should not be higher than that actually required to give the power viz :—the steam valve open wide and the revolutions of the engine set by linking up. Allowance should always be made for sufficient pressure to properly manipulate the engine in case of emergency.

Advantage should also be taken of using all fuel saving appliances, such as feed heaters, evaporators, and steam jackets, due regard being given to the various speeds and conditions under which the engines are working. When an evaporator is fitted and no feed heater, it is an economy to lead the drain from the heating coils into the feed tank and thus save some of the waste heat. When evaporating for feed make up, the *gained* steam should also be used in this way. Care should be taken to minimise as much as possible all loss of heat which can be usefully applied, and also the loss of fresh water.

The highest point at which the link can be worked economically can be seen by taking a diagram. When a loop is found at the admission corner, the limit is reached. It is generally convenient to have a marked graduation for linking up, and an index or pointer to shew the amount of travel of the piston at the point of cut off. This gives the ratio of expansion, by a simple calculation neglecting clearance.

It might be pointed out here that the better management of the machinery has an enormous influence on the economy of the fuel, and instances have been known, where by better management alone, the "radius of action" of a battleship has been doubled. A fruitful cause of excess expenditure of coal is caused by necessary fleet manœuvring, especially when at varying speeds. A fleet steaming in "line ahead" will burn considerably more coal than one steaming in "line abreast." In the first case the *following* ships have to exert varying powers, and at certain times, such as when altering formation, to work at very high powers for short periods and this is an expensive manner of working.

CHAPTER XV.

PROPULSION.

THE resistances of the ship to motion may be summed up as three in number.

(1.) Skin Friction.
(2.) Eddy making.
(3.) Wave making.

(1.) Depends on the condition of the surfaces and depth of immersion. A dirty bottom to a ship will reduce the speed considerably, sometimes two knots or more. For this reason the ship's bottom should be kept as clean as possible and the surface as smooth as possible. The propellers especially should be kept clean and smooth and if of bronze or brass, should be kept bright, and polished as frequently as possible, a diver being employed for this purpose if the ship cannot be docked.

(2.) Eddy making is caused by the propeller not acting directly on the water but obliquely, a certain amount of the power being expended in churning the water. When a ship is towed through the water, the water will open out at the bow and follow round the sides of the ship in well defined currents, called stream lines, closing in again under the stern, so that the counter pressure under the stern thus tends to balance the head resistance. If the run aft be not sufficiently fine to allow the water to close in under the stern, quickly enough, an eddying wake is formed, and this increases the direct or head resistance, by tending to diminish the balancing action of the water under the counter.

(3.) From the bows of all ships in motion, waves are formed, to a greater or less extent, which in most cases pass away from the ship in divergent directions, without producing

a corresponding reaction under the stern; and the energy expended in creating these waves is evidently wasted.

Within ordinary limits the *resistance* varies as the *square* of the speed, but the *power* required to overcome the resistance and propel the ship at any speed *varies* as the *cube* of that *speed.*

Let S = speed in feet per minute.
R = resistance in pounds at that speed.
Then $R = S^2 \times K$, where K is a constant or co-efficient.

Multiply both sides of the equation by S.

Then $R \times S = S^3 \times K$.

But $R \times S$ is the work done in foot pounds per minute in overcoming the resistance R, through the space S, and divided by 33,000 is equal to the horse power required to drive the ship. This law only holds good for the same or similar ships, but it is always useful in calculations. Thus, if we know the horse power for full speed, the equivalent can be calculated for any lower speed, and generally it will be found very approximate to that actually indicated by the engines.

Indicated thrust.—The indicated horse power does not give a true measure of the work performed by the propeller as it involves the efficiency of the mechanism and the efficiency of the lines of the ship in the same expression.

Mr. Froude therefore reduced this to a force factor by dividing it by the speed of the propeller and called the result the *indicated thrust.*

The Indicated thrust therefore in pounds

$$= \frac{\text{I.H.P} \times 33{,}000}{\text{Pitch} \times \text{N}}$$

$$= \frac{2 \times \text{P} \times \text{L} \times \text{A} \times \text{N}}{\text{Pitch} \times \text{N}}$$

$$= \frac{2 \times P \times L \times A}{\text{Pitch}}$$

By calculating the indicated thrust, from the horse power for certain speeds a curve may be constructed, which has for its vertical components the thrust indicated in pounds

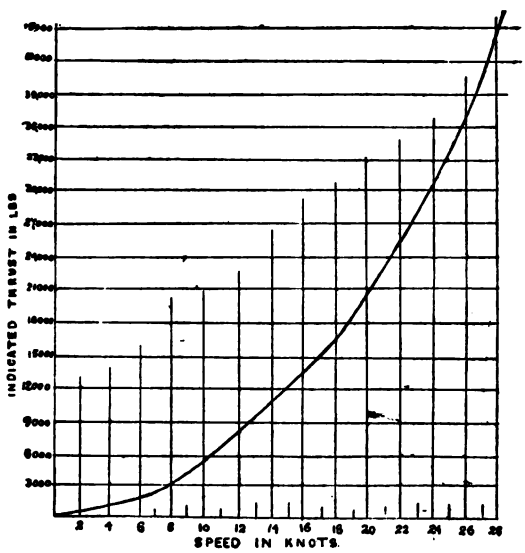


Fig. 124.

(or tons), and for its horizontal components the scale of speed in knots, as shewn in fig. 124. By the proper use of the curve the equivalent thrust can be obtained for any required speed.

Curves should be constructed for many purposes by the engineer instead of, or in conjunction with, tabulated results. Thus taking the base or horizontal line to represent to scale, the speed in knots or in revolutions, and setting up ordinates vertically to represent the coal consumption for a few known or ascertained speeds, a fair curve can be drawn which will shew at a glance the *coal consumption* for any speed. (See fig. 125.)

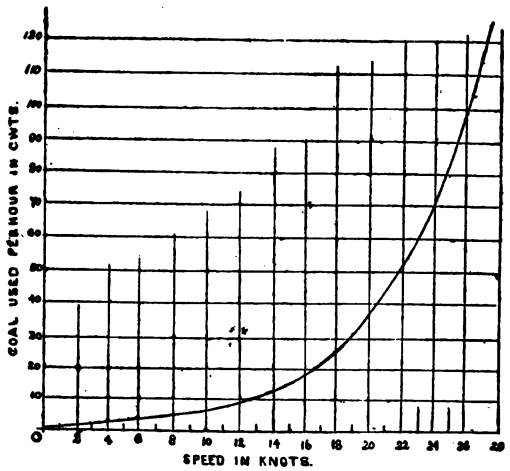


Fig. 125.

By combining the speed and the horse power a curve can be constructed, that will shew the power for any speed required, and if one is constructed it will be found that this curve will cut the zero vertical ordinate, at a certain point which will represent the horse power required to overcome the frictional

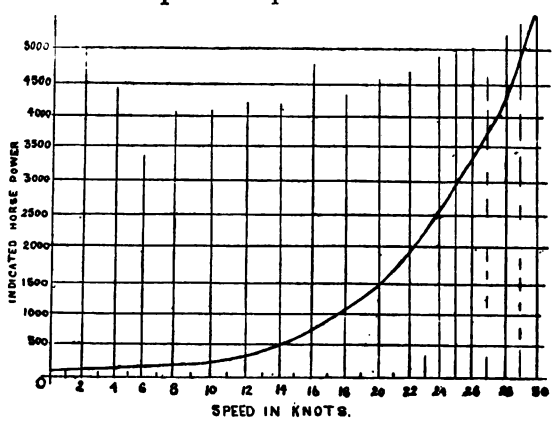


Fig. 126.

resistance, or as it is usually termed the initial friction of the engine. A good idea of the condition of the engine and its general efficient working order, may be obtained by comparing results

in a curved form from time to time. If the initial friction has increased it will be seen that some part of the mechanism, is absorbing an undue amount of the power given out by the engines, either from leakage or friction or improper working.

By combining the coal consumption and the horse power a curve may be obtained which will shew the most advantageous rate of expansion for each speed, and that which will probably give the best result for each speed ordered.

In many other ways curves can be used with great advantage for obtaining the best possible results and they shew graphically a means of obtaining these results which if tabulated only would require some difficulty to unravel.

Paddle wheels.—The simplest form of propulsion is by the paddle wheel and it is also under good conditions of wind, weather and proper immersion the most efficient. The *radial* paddle wheel is the most easy to construct, the floats being secured directly on to the arms from the centre of the wheel, and as the name implies being exactly radial from that centre. It is evident that the only time at which the float acts perpendicularly to the water, so as to give the most direct thrust is when the radius arm is perpendicular to the water, that is, vertical: the surface of the water always being considered horizontal. At all other times the thrust is not direct but oblique and therefore is not so efficient.

To overcome these objections the *feathering paddle-wheel* was introduced. This is shewn in the diagram (127), A, being the centre of the wheel and B, another centre, on about the same horizontal line but before the wheel centre. The action is then the same for all or one float. BK, is a radius bar and KC, is connected to it at K, by a pin joint. KC is a lever with its fulcrum at L, which is a point on the wheel circle. In some cases L coincides with C. Then radius arm BK, is constrained to work in a circle round B, as centre, and at the same time

C, is constrained by the radius arm AC, to work in a circle round A, as centre. It will then be found that the figure will be somewhat as shewn in the diagram, and that as the floats

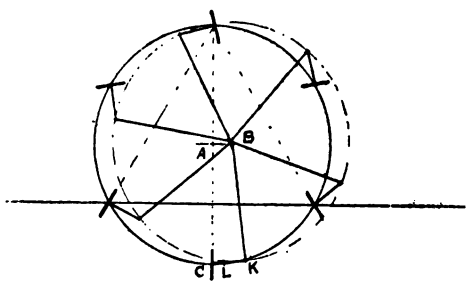


Fig. 127.

enter and leave the water they are not actually vertical but are considerably nearer the vertical than in the radial paddle wheel.

To prevent the radii of the two circles cutting the shaft, (in theory), the shaft is cranked or as is more general in practice the wheels are *overhung*, being supported by a bearing on the ship's side only and not on the paddle box. The feathering motion can then be applied by attaching the radius rods to a sheave, working on a pin carried by a bracket which is fixed to the outer side of the paddle box, in the proper position eccentric to the wheel.

Although a most efficient means of propulsion the paddle-wheel has many disadvantages, the principal are.—

(1). Variation of effect when ship is rolling or pitching, the floats sometimes being immersed too much and at others too little.

(2). The draught of water must be accurately maintaintained or the floats will, if the ship be sufficiently weighted, be immersed to such an extent that propulsion will be difficult or inefficient. If weight be taken out the floats cannot get sufficient hold on the water. In long voyages the

difficulties of immersion must always be present, for the coal burnt during the voyage would alter the immersion or draught of water considerably.

(3). The paddle-wheel is always exposed to shot and shell and this in a man-of-war is sufficient to cause its rejection.

On the other hand the screw propeller although not quite so efficient has none of these objections. It is little affected by difference of immersion and being below the surface of the water is protected to a great extent from the effects of shot and shell, and in addition the propelling engines can also be kept below the water line.

Jet propulsion.—Various attempts have been made to propel ships by means of a jet of water, the water being drawn in at the forward part of the ship and ejected at the after part or sternwards. The orifices would require to be very large and experiments so far have not justified their use, in fact rather the reverse. It is possible however that when the screw propeller begins to shew signs of being inefficient, and it appears to be approaching that stage, that further attempts will be made and perhaps with greater success, as theoretically better results should be obtained.

Two similar boats built by Messrs. Thornycroft one being propelled by a screw, and the other by a turbine, with a horse power of about 170 indicated by each, attained $17\frac{1}{4}$ knots and $12\frac{1}{2}$ knots respectively. In other words the screw propelled boat would attain about the same speed for *half* the power.

The screw propeller is to a limited extent an extreme example of the jet propeller in some ships. The French ironclad "Jauréguiberry" has two propellers and the form of the ship is made so that they work in partial tunnels. This

form is adopted to give a better run of the water to the propellers. If the tunnels were complete the propellers would simply perform the function of helical pumps.

The screw propeller.—Is the usual means of propelling ships when required to be sea going. It is placed under the counter or after part of the ship, and is generally entirely immersed so that it is protected to a very large extent from shot and shell. The name *screw* is given to a set of metallic blades, placed obliquely on a horizontal shaft, and revolved by means of the engines.

The form of each blade may be conceived by imagining a straight line to be always perpendicular to the shaft, while it travels along it, and at the same time revolves round it.

Thus let A B be the shaft, fig. 128, (which, when working, would be horizontal), and suppose the line A P, to commence travelling along A B, always remaining at right

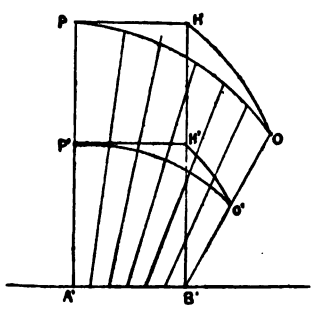


Fig. 128.

angles to it, while at the same time it revolves round it; so that when A comes to B, P has come to O instead of being at H, where it would have been, had it not revolved through the angle H B O.

Length of the screw.—The space A B along the axis, which is occupied by the screw blade is called the length of the screw.

Angle of the screw.—The angle P O H, between the outer edge O P of the screw, and a plane perpendicular to the axis of the propeller, is called the angle of the screw. It will be noticed that the *angle* P^1 O^1 H^1 *increases* as the *radius* A P *decreases.*

Pitch of screw.—If A P makes a complete revolution round the axis A B continuing its uniform motion along the axis, the distance travelled along A B would, in such case be called the pitch of the screw.

Diameter of screw.- -This the diameter of the screw is the diameter of the circle described by the extreme end of the screw, when the pitch is zero. The area of this circle is called the *disc area.*

NOTE.—The extreme point of the screw will, when in motion, have a path represented by a uniform spiral described on a hollow cylinder; the diameter of this cylinder being the diameter of the screw and the longitudinal distance between the spiral curves will be the pitch.

In other words take an ordinary screw used in carpentry or other work and screw it into a board, the distance it

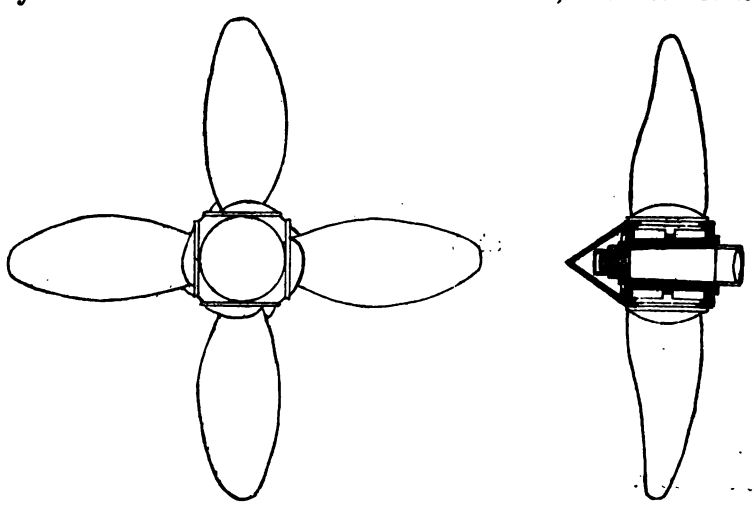


Fig. 129.

will advance into the wood in one exact revolution will be the pitch, and the outside diameter of the screw thread will be the diameter.

The screw propeller is neither more nor less than part of an actual screw thread of somewhat coarse pitch. A type of screw propeller is shewn in fig. 129.

Slip of the screw.—As already stated, the screw propeller, if working in a medium that could not yield, would advance a distance equal to the pitch during each revolution. Water however yields to a certain extent and therefore it is found that the ship does not move at the speed which would result in an unyielding medium.

Let S = speed of ship.

s = speed of propeller.

Then $s - S$ = slip of screw.

and $\frac{s-S}{s}$ = slip of screw expressed as a fraction.

Therefore per-centage of slip $= \frac{s-S}{100 \times s}$

This however is the *apparent* slip, for the screw is acting on a medium already set in motion by itself or by the ship. The velocity of this stream must also be considered, and as this depends very much on the shape of the ship and other varying conditions, the *actual* slip is very difficult to obtain. Generally when the slip of the propeller is spoken of, it refers to the *apparent* and not to the *real* slip.

Negative slip.—From the nature of the medium in which the screw propeller works, it is clear that in every case there must necessarily be *positive real* slip, but in some particular instances the *apparent* slip has been *negative*, that is the speed of the ship has exceeded the speed of the propeller. Generally negative slip is not considered any gain in efficiency

but rather a loss, as it shews that there is actually a diminution of pressure of the water on the stern of the ship, which more than counter-balances the increased thrust on the screw propeller itself. Negative slip is observed generally when running in shallow water, and is more frequently observed in the Suez Canal than in other places.

Area of the screw.—The area of the surface of the blades of the screw is called the area, or more properly the *blade area* of the screw. Each blade may be considered as an inclined plane, of which the top surface is the blade area, the height is the pitch and the base is the diameter of the screw. It is seen that the blades act obliquely on the water, and therefore some portion of the force must be expended in churning or rotating the water round the shaft, while the greater part is spent in pushing the ship forward. If therefore the pitch is great it follows that the churning action would also be great, and therefore for a certain speed it is better to have a fine screw (small pitch) revolving at great speed, than a coarse pitched screw at a slower speed. The limit would appear to be obtained when the friction of the blades themselves in passing through the water reduces the advantage of fine pitch to a minimum.

The screw propeller acts at a very small depth below the surface of the water and consequently the force acting and tending to fill up the space left in the wake of the ship and of the propeller, is very small. Practically it may be considered as that due to the atmospheric pressure, or about 15lbs., per square inch. This pressure is therefore approximately, the limiting amount of thrust that can be put on the propeller blades. To obtain a fair efficiency from the propeller the limit should be about 11lbs., per square inch. Above this amount it appears that the propeller becomes inefficient and a large amount of horse power is absorbed in churning the water without propelling effect. With slow moving ships, where

the acceleration, due to the *head*, is above that due to the speed of the propeller through the water, a greater thrust pressure per unit of area may be allowed with efficiency.

The effect of increasing the blade area has been most marked in some instances where previous efforts with smaller blades had been unsatisfactory.

The pitch of any screw propeller is generally measured practically by the method described below (fig. 130).

The cap at the end of the shaft is removed and a radius bar CO, fixed at the end C, to the end of the shaft. The point C, is made coincident with the centre or axis of the shaft. When the bar is moved it should always lie in a plane perpendicular to the shaft. A number of parts of circles, at different radii, are described on the propeller blade by means of a bar OA, sliding through a connection, which connection may be clamped at any radius, on CO. The bar OA, must always be parallel to the axis of the shaft, so that the circle described from C as centre has CO, (=CA, in upper figure) as radius. Denote any radius CA, by r. By means of a circle on the end of the shaft or propeller boss the radii may be set at equal angles. Let each of these angles, through which the bar CO is moved, be equal to θ.

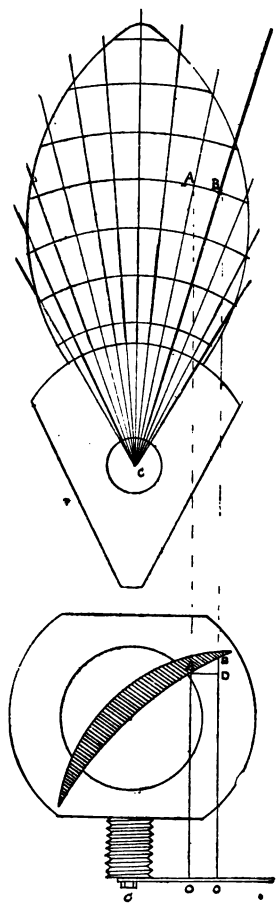


Fig. 130.

(NOTE.—In the upper figure, or elevation, the point B is coincident with the point D; but the angle ACB, is not quite equal to the angle ACD, although it approaches it very closely when θ, is very small.)

Suppose the pitch is required at any part AB.

Then measure OA, and OB, accurately. From which we get BD = OB − OA. In one complete revolution the point O, describes a circle the circumference of which circle is $2\pi r$ of which AD is a part. This circle is cut into $\frac{2\pi r}{AD}$ equal parts by the radii. Also in one revolution the point A, travels in a direction parallel to the axis a distance equal to the pitch of the screw and is divided into $\frac{2\pi r}{AD}$ equal parts each part being equal to BD.

Therefore, the pitch, at any part AB,

$$= BD \times \frac{2\pi r}{AD}$$

where $\pi = 3{\cdot}1416$.

Or, the pitch

$$= \frac{BD \times 2\pi}{\theta}$$

where $\pi = 180$ degrees, and the angle θ is known.

For example, let $\theta = 7\frac{1}{2}°$,

Then, the pitch $= BD \times \frac{360}{7\frac{1}{2}}$

$$= BD \times 48$$

That is, the pitch is 12 inches for every $\frac{1}{4}$ of an inch of BD.

The pitch is found for every point, where the radii cut the circles, in a similar manner.

The mean of the pitches thus obtained is called the mean pitch.—A *more approximate mean* is obtained by calculating the mean pitch at each radius and the mean of the

means thus found is the true mean. The greater the number of radii employed the nearer will the approximation be to the correct mean.

Generally this second method will give a smaller mean pitch than that obtained by the first method.

There appears to be no particular law laid down as to the best disposal of the pitch. Some makers employ an absolutely true thread, the pitch being perfectly uniform throughout. Other makers employ a screw with the pitch somewhat larger towards the following edge, and also increasing towards the tip of the blades. It is probable that the latter method will grow in favour, and general evidence appears to point towards this type of pitching, as being more that required by theoretical considerations as far as has been confirmed by practical experiments. The difference however does not appear to be great.

CHAPTER XVI.

VENTILATION, WATER-TIGHT DOORS AND PUMPING ARRANGEMENTS.

Ventilation.—This is a matter of first importance in all parts of the engine room department. If the simple laws of nature are followed the ventilation of any part can be easily carried out. But in some vessels these laws have been so contorted and strained, as to apparently prove ventilation a difficult matter to cope with. The first consideration in ventilating any compartment is that the *supply* or *cold air* should enter the compartment at the bottom and the *exhaust*, or *hot*, air, should be carried off by an exit at the highest possible point. Generally the bottom or floor of a compartment is a more or less fair surface, either perfectly flat or sufficiently so, to distribute the down coming air fairly evenly over the whole compartment. The roof of the compartment is however a more difficult matter, and owing to the beams of the ship and many pipes and similar obstructions, the surface is not very fair.

In this case a little discrimination can fix a point at some little distance from the supply, so as to give a continuous motion of the air in one direction. Thus in an engine room the supply should enter near the condenser or low pressure cylinder, and the exhaust should be near or almost immediately over the high pressure cylinder or main steam valves, this latter being generally the hottest part of the engine room. Attempts made to supply cold air to these hot places direct from the deck, are always failures, and the most efficient

manner of cooling them is by making them uptakes or exhausts, and obtaining the supply from some cooler spot. The engine room is generally ventilated by means of cowls and long trunks or shafts leading down to the part required. The lead of these trunks should be straight and vertical, every bend reduces its ventilating efficiency.

Each right angle bend reduces the efficacy of a ventilator from 80 to 90°/₀ and very few of such bends will reduce the ventilation to almost nothing. Trunks for exhausting the hot air from the engine rooms are sometimes led into the supply for the forced draught fans. When these latter are in use, they reduce the temperature in the engine room considerably, but they are objectionable, as a bulkhead otherwise watertight has to be pierced. The reduction of temperature in the engine room is obtained at the expense of a rise of temperature in the stokehold and complaints arise from the insupportable heat in the latter. Stokeholds fitted with forced draught seldom have any uptake or exhaust arrangement, except that through the ladderways or gangways and through the fires. The supply is therefore generally in the upper part of the compartment, and the ventilation is *forced* downwards as opposed to natural circulation. With this system of ventilation, as might be expected, the air is moved in streams from the fans to the furnaces, and many parts are not touched by these streams. These parts are generally hot and inconvenient, but the general working platform is cool and as a means of cooling the working parts of the stokeholds the system is good.

Induced draught produces more of a forced than a natural direction of flow, but there are few pockets in which the hot air can get congested, and for general working conditions and as a means of keeping the ship near the boilers cool as well as the stokeholds induced draught has many advantages. The air supply for the furnaces is drawn from all parts of the boiler rooms including the casings over the boilers. The hot

air drawn from the tops of the boilers does not appear to raise the general temperature of the stokehold so long as the hatches or other means of ventilation from the deck can be kept open.

The ventilation valves and other means of closing the bulkheads and decks when they require to be water-tight are, in the navy, in charge of the Engineer, and therefore a little study of the general system employed is given here. The usual means of ventilation are separate of trunks for supply and exhaust, each compartment having its supply and exhaust from the main trunks. In the older vessels the branches are led into the main trunks by a T piece and from this cause alone the ventilation is imperfect.

The branches should be led into the main trunks at an angle of about 30 degrees, so that the direction of motion of the air in the trunks, should be the same with little or no confusion of currents. If the main exhaust trunks are then turned, by a gradual bend upwards, into the funnel air casing, a good and efficient ventilation should be maintained. The supply is given by another trunk and branches.

This system of a trunk supplying about one third of the ship is a very dangerous one, as when one compartment is flooded, the valves being closed, the other compartments must be left entirely without ventilation. Below the water line or armour or protective deck, there should be as few holes as possible in bulkheads either transverse or longitudinal. Water-tight doors are not a necessity, except for coal bunkers, below the water line and large sluice valves are more a source of danger than a convenience.

The only other danger is the ventilation trunk, and this should be dispensed with, and each main compartment should have its own supply and exhaust, direct from and to the upper deck, and if these cannot be fitted at the extremities of the ship then each compartment should have its own trunks led along as high as possible above the water line. With the

curved steel deck the exhaust system should be a simple matter, the hatches, being generally made at the higher parts, would carry off all vitiated air.

Generally a naval ship is divided transversely into from twelve to twenty main compartments by bulkheads which extend from the keel to the water line, and then continue again above the water line to the upper deck. Each of these main compartments is sub-divided into many smaller compartments. If the ship is struck at the junction or bulkhead between two main compartments and these filled with water, the ship should still keep afloat and be manageable, but if owing to some ventilation valve being left open, as many must be in some ships, for the supply of the magazine men and others, other compartments are flooded, and the ship will probably be disabled, and may sink. The magazines can be exhausted through the barbettes or turrets in the larger ships, and in smaller ships cowls can be used for exhausters without referring to any other compartment. In action there are many parts of the ship which should be shut up and hermetically sealed until a port is reached, and it appears that only the magazines and the engine and boiler rooms should be necessarily open for purposes of ventilation. The curvature of the protective armour deck lends itself particularly to this arrangement, and ships which are built with holes, (whether fitted with water-tight doors or not is of little consequence,) in their main transverse or longitudinal bulkheads, are unreliable as floating platforms. With the bulkhead below the water line perfectly intact, a ship should keep afloat for some considerable time even after being badly rammed or torpedoed. For these reasons it is desireable to make each compartment self supporting as regards ventilation. Any other system reduces the value of the ship considerably as a floating structure.

The movement of the air due to natural causes is not very great in the supply and exhaust pipes, and disregarding

that given through the cowls due to motion of the ship, we have simply that due to the difference in weight of the external air and that of the compartment ventilated, added to the efficiency gained by the height of the ventilating shaft. Now in a well ventilated compartment the temperature should be maintained about the same as that of the outer air. This would give little draught due to difference of temperature alone so that the height of the ventilating shaft must be relied on to give a good result. Thus when the ship is stationary it is requisite for good ventilation that the leads should be as direct as possible, to give the maximum flow due to the *head* obtained by the trunks leading to the cowls. In the parts of the ship most requiring ventilation some steam machinery is generally to be found, so that it is advisable to place the the exhaust opening over or nearly over, the engine or steam pipes, as the case may be, and the heat thus set free will generally engender quite sufficient current for ventilating purposes. The advantage of additional height should be taken into account and the fullest use made of it wherever possible. The cowls should be masked by the funnels as little as possible for generally it is found that when ventilation is most required the wind is not right ahead and at this time the cowls are almost the only means of obtaining fresh air between decks and elsewhere. If the means of supply are in excess of the means of liberating the foul air, it leads to pockets or corners of foul air and therefore we should look to the means of exhaust as the best ventilator. If the exhaust system is efficient it will keep up a good supply, but a good supply will not act in the same degree and keep up a good exhaust.

Summing up the results of the foregoing observations, the best system of ventilation is obtained when:—

(1.) The leads for supply and exhaust are direct and vertical.

(2.) All bends are very gradual and the trunks are joined at an acute angle so as to give the same direction of current.

(3.) The supply is taken down near the bottom of the compartment and the exhaust taken from the top.

(4.) The vertical height is as great as possible.

(5.) The means of exhaust are in excess of those of supply.

Water-tight doors are fitted in nearly all ships but generally they are most numerous in war ships. There are two principal methods of fitting them. In one the doors are worked by screw or pinion gearing, and in the other the doors are hinged and are secured by hand clips working on small inclined planes or wedge pieces.

The geared door is generally vertical, wherever sufficient height can be obtained. It is raised and lowered by a square threaded screw, which can be manipulated, both at the door itself and, by means of rods from the main deck or above the water line. If the gearing is direct the door will fall of its own weight, and special means are fitted for balancing the weight. In some instances mechanism has been fitted for closing the doors easily and quickly.

There is no particular speciality in these quick closing arrangements, and although many attempts have been made to introduce them in war ships, some failure has generally been due to the inaccessibility of the mechanism and imperfect design of the details. Better results are expected from the latest design, which is being fitted in some large vessels. From a point of view of welfare to the service, our energies might be directed to the elimination of the water-tight door as well as to a method of quick closing.

Instructions have recently been issued on the working of water- tight doors, pointing out in detail the precautions which

are to be observed. When ships are under weigh or in the vicinity of other ships under weigh, or when there is a probability of grounding or collision, and when ships are preparing for action or evolutions under steam, all coal bunkers, store rooms and water-tight compartments not actually in use, are to be kept closed. The collision bulkhead is always to be kept intact, and all empty water-tight compartments are to be kept closed. In the case of those compartments opened for the supply of coals or stores, or for the purposes of ventilation, they are again to be closed as soon as possible and reported so.

When manœuvring, and when entering, or leaving, a port or anchorage all the water-tight doors, sluice valves and scuttles which can be closed without inconvenience to the working or ventilation of the ship are to be closed.

In the case of doors necessarily left open, men are to be stationed so as to close them when expedient at a moment's notice. At night and in fogs similar precautions are to be observed, all compartments being closed which are not in use for working or sleeping purposes. The stations for collision are in future to include men for closing gun ports and armoured doors, and if needed special ladders are to be rigged to facilitate traffic.

Sluice valves are fitted for draining water from one compartment to another, and there is no reason that these should ever be opened except to keep them in working order, or on special occasions for draining small quantities of water when all other means have failed. The normal condition of these valves should be *shut*. In case of a collision or other accident, where the area of the hole or leak is beyond the control of the pumping power of the ship they should not be opened. The first efforts of all should be directed not to getting the water out but rather to preventing the water coming in. When the leak has been stopped as far as possible and any excitement

has subsided efforts may be directed to pumping out the water. It should be taken into account that the largest pumping power fitted to any ship will barely control a leak equal to a hole *one foot in diameter* and twenty feet below the water line. If the leak is forward the ship will sink by the bows perhaps four or five feet and to get the pumps to work on this through the sluice valves more water must be admitted through the length of the ship up to the engine room. For this reason alone it is preferable to use any other means of pumping out the leaky compartment, than through the sluice valves. In the larger ships of modern construction a large pipe is fitted in duplicate on each side of the middle line for pumping purposes. These are generally termed the *main* drain or *suction pipes*. At each bulkhead through which these pipes pass a shut off valve is fitted, and a branch is fitted with a suction box and non-return valve in each compartment. All the valves in these pipes are generally fitted in such a way that they can be manipulated from above the water line. In some of the older ships these pipes were carried through the *double bottom* but now the practice is to carry them along the bilge above the *inner bottom*, in which position, in case of grounding, they are less liable to injury.

We must rely in the first place on the water-tight compartments to prevent a ship sinking in case of accident, and not to any pumping arrangement however efficient.

Efficient pumping arrangements may delay the sinking of the ship, it may be indefinitely, but the compartments must be fairly water-tight to admit of this.

It is important to remember that when the leak is in an engine room (where the great pumping power is situated) or in the stokehold (where the steam is generated) that the leak must be kept as low as possible to allow for moving the main engine to reach a port or shallow water.

Little or no reliance can be placed on outside assistance. The greatest possible depth from which a pump can draw water is thirty three feet and twenty five feet is perhaps a high estimate for the depth from which a pump under ordinary conditions will draw water.

The velocity with which water will enter a ship at any depth, h, (or velocity due to a head, h,) is given by the formula,

$$V^2 = 2.g.h.$$

where $g = 32$ (approximately.)

or, velocity $= 8\sqrt{h.}$

When the area is known it is a simple matter of calculation as to the amount. For this calculation we may take that one ton of sea water occupies 35 cubic feet, or, one cubic foot of sea water weighs 64 pounds. One gallon of fresh water weighs ten pounds, exactly, and sea water weighs about three per cent., more than fresh water.

The means that can be used for pumping out the ship are generally,

(1.) Main circulating pumps.

(2.) Fire engines (separate pumps for this special purpose.)

(3.) Bilge pumps, (these are small pumps used for general purposes.)

(4.) Steam ejectors.

Of these the main circulating pumps are the principal and command a large body of water, but they are not reliable suction pumps, and special means are adopted for charging them. They are situated in the engine room, and generally are not connected for pumping out any compartment but the engine room itself, except by drainage into the engine room bilge, through sluice valves.

The fire engine is a special pump fitted for fire purposes but it is fitted also to pump from the bilge. It is not fitted in any but the largest ships.

Bilge pumps are fitted in all ships, sometimes, but not now usually, worked from the main engines. Two are fitted in each engine room as a rule and they can be used either for fire or bilge purposes. Generally one or more is fitted for circulating water through the distilling condensers.

The *Bilge Ejector* shewn in fig. 131, is fitted principally in small ships but a larger size fitted with several nozzles is used in some large ships. There is only one objection to this system and that is the loss of fresh water If properly fitted

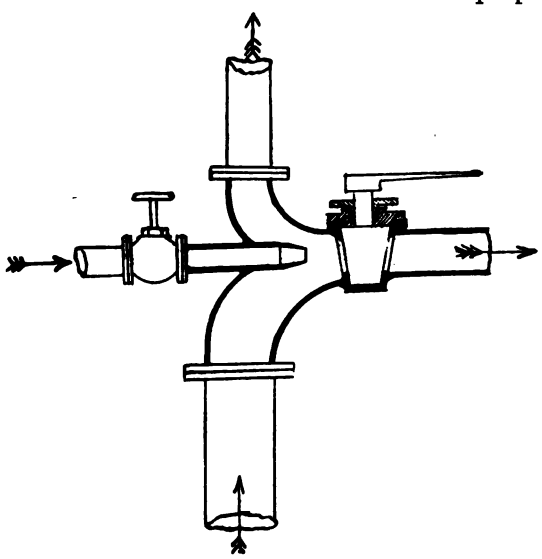


Fig. 131.

so that the suction is well covered with water and the ejector fitted at or about the same level as the suction they are very useful and large quantities of water can be ejected. The quantity of steam absorbed is considerable and the main engines would require to be slowed down when they are used They, however, take up very little room or space, are very light and there is no mechanism to get out of order. The valves connected with them should be capable of manipulation from the upper or main deck. The top pipe, shewn in sketch,

is connected to a bilge pump, and is therefore shut off when the ejector is used.

Sea connections and flooding valves.—In warships, valves and cocks connected direct to the sea, are generally provided for flooding the magazines when required. The flooding valve next the magazine itself is generally locked so that it cannot be tampered with. One main sea connection valve is usually provided at each end of the ship and branches are led away for the various magazines, each branch being controlled by a separate locked flooding valve.

The sea connections throughout the ship are now generally ordinary stop valves, made entirely of special brass. A pipe where necessary connects the valve with the outside of the ship. On the outside of the ship around each orifice a *zinc protector* is fitted. The zinc does not prevent galvanic action, but is subject itself to corrosive action and as it is more susceptible, attracts to itself all or nearly all corrosive or galvanic action. All zinc protectors are renewed at every possible opportunity, when the ship is docked.

One of the many duties of an Engineer Officer in the Navy is that of disposing his staff for their various duties *under steam*, and in case of *fire*, *collision* and *general quarters* for action.

A watch and station bill is prepared before any ship is commissioned and should be such that all that is required to complete it, is to fill in the names of the men and various particulars relating to the men.

Without in any way wishing to "lay down the law" on this subject, the author ventures some remarks on the lines on which a watch and station bill may be prepared.

The whole of the engine room staff is divided into three sections or watches, one of which is, at sea, always on duty in the department. This gives an average of eight hours on duty

in every twenty four. They go on duty in rotation and are known respectively as the first, second, and third steaming watches.

The watch on duty in the engine room department at any time is called the *watch on.* That watch which was relieved by the watch on, is called the *watch last off.* The other watch is called the *watch longest off.*

Each watch is divided into groups under petty officers, and in making out the stations for various duties it is generally convenient to keep each group intact, and to detail them so that they have as little distance to move as possible when going from *watch on* to fire stations or to collision stations. or from fire stations to general quarters.

At close water-tight doors, or **Collision stations.**—The *watch on* close all doors in the engine rooms and stokeholds and bunkers that may be open; the *two watches off* go to their stations and close all doors and other water-tight fittings at those stations.

Each close water-tight door station should be made to as nearly as possible coincide with a water-tight bulkhead or group of bulkheads. The petty officer in charge of the group or station is then responsible that the whole bulkhead is intact.

The system of "one man, one door" is a most dangerous one for although eleven fittings may be closed on a bulkhead, the twelfth may be left open. By means of the group formation the men can close all doors if one man or more is absent.

At **stations for fire,** it is usual for the *watch on* to prepare all necessary steam pumps, for pumping water through the fire main, and to start them when ordered.

The *watch last off* assisted by the *watch longest off* go to fire stations and rig hoses ready to extinguish the fire. After

the hoses are rigged the *watch longest* off prepare to close water-tight fittings, particularly ventilation valves when ordered.

The fire stations should be numbered from the bow to the stern, each rising main being a station. The petty officer in charge is made personally responsible for the opening or closing of the valve generally situated immediately below the armoured deck which commands the whole of the branches on the station.

Thus, we have stations as below

No. 1, upper deck,
No. 1, main deck,
No. 1, Lower deck,
No. 1, Platform deck,
No. 2, Upper deck.
No. 2, Main deck,
and so on.

There is generally a rising main in each main transverse compartment, and it will be found that these stations can be made to coincide with those for closing water-tight doors.

A small party or parties generally under the personal direction of an officer is detailed for flooding the magazines if called on.

At general quarters for action.—The "watch on" close water-tight doors as at collision quarters, and then prepare the steam pumps as at *fire quarters.* The *watch last off* go to *fire stations* and rig hoses and then "fall in" near their stations as a fire brigade. The *watch longest off* go to *collision stations* and close all water-tight doors and fittings except those necessary to the working of the ship. The watch then stand by to close the doors, etc., left open. These doors should be shewn in red ink on the station bill.

It is probable that when an action is imminent all doors would be already closed and all hoses rigged. By making the fire stations and collision stations coincident, one watch might, with safety to the ship, be withdrawn from these stations and sent to assist the "watch on" in the engine rooms and stokeholds. This provides for the very necessary re-inforcement of the men on the fires and attending the engines. In an action no officer or man could possibly be *off duty*, and every one must remain at his station until the action is finished.

In preparing the watch bill, a method, which leads to the least confusion, is essential. For this reason no person's name should occur on it more than once. Two bills are generally prepared, one gives the stations with the names, and the other enumerates the various water-tight doors, sluice valves, ventilation valves, drain valves and other water-tight fittings. These are generally arranged in groups, numbered in a coincident manner with the fire stations. A list of the men arranged in three columns corresponding with the watches and arranged in their proper groups is usually placed on this bill. Sometimes index numbers are used referring to the watch bill.

The headings for a "Watch and Station bill" are shewn below.

WATCH AND STATION BILL.

Index No.	Steaming Station.	FIRST WATCH.					SECOND WATCH.					THIRD WATCH.					Fire and Collision stations.	Index No.
		No. of Hmk	No. of Mess.	Name	Rating.	Harbour Stations.	No. of Hmk.	No. of Mess.	Name.	Rating.	Harbour Stations.	No. of Hmk.	No. of Mess.	Name.	Rating.	Harbour Stations.		

APPENDIX TO CHAPTER III.

THE results of some evaporative tests made with a Blechynden water-tube boiler, may be of some interest and are given below. They do not differ to any great extent from those of other water-tube boilers of English design. It is probable that at least 100 I.H.P. can be developed per ton weight of boiler under the usual conditions, and with a better quality of coal, as in these tests the boiler was not clothed and the coal used was of low calorific value. Mr. Blechynden has adopted for the latter types of his boiler a proportion of about fifty square feet of heating surface to one square foot of grate; this will reduce the rate of combustion per foot of grate, and should give a better evaporative result. It may be remarked here that the proportions of water-tube boilers in general are still in a state of evolution. From the results given below and others which it has been my fortune to analyze, it appears that the amount of coal burnt per square foot of grate should not exceed 60 to 65 lbs., and that the heating surface should be at least 50 times the grate surface area, and it is probable that to obtain the best results this proportion may be increased by 50 per cent.

Blechynden water-tube boiler, evaporative tests.

Date of trial.		16 August 1895.	14 August 1895.
Boiler pressure	lbs.	200	180
Grate surface	sq. ft.	37	37
Heating surface	,,	2430	2300
Heating surface per square foot of grate surface		65·7	62·2
Coal burnt per square foot of grate per hour ...	lbs.	72·8	41
Feed water, per hour	lbs.	18300	12500
Temperature of feed	Fahr.	70	62
Evaporation per lb. of coal	lbs.	6·81	7·8
Equivalent evaporation per lb. of coal *from* and *at* 212° F.	lbs.	8·2	9·4
Temperature in uptake	Fahr.	700 to 840	
Evaporation per square foot heating surface ...	lbs.	7·54	5·45
Equivalent evaporation per square foot of heating surface at 212° F.	lbs.	9·2	6·55
Heat units transmitted per square foot of heating surface per minute		148	105·5

QUESTIONS.

1. Show, by sketches, how you would arrange the furnaces and combustion chambers of a double-ended boiler, and explain how the different parts of the combustion chambers are stayed.

2. Explain how a boiler is liable to suffer from undue haste in raising steam, and describe fully the precautions that are necessary when steam is being raised?

3. What are the advantages of using corrugated furnaces? Describe how you would fit this form of furnace to the combustion chamber.

4. Show, by sketches, how the cylinders of a set of horizontal engines should be attached to the engine seating.

5. Sketch the piston rod, crosshead and shoe for an engine, and show how the shoe is fitted to admit of adjustment.

6. Describe the different kinds of packing used in the Navy, and for what glands are the various descriptions most suitable.

7. Enumerate the valves in direct connection with the sea which are necessary in the engine and boiler rooms, and state briefly the purpose for which each is fitted?

8. State the reasons which have led to the adoption of duplicate centrifugal engines and pumps, and show how the pipes should be arranged so as to obtain the full advantage of duplication.

9. Describe fully a method of determining practically the pitch of the screw propeller.

10. Describe the ordinary distilling condenser as fitted to ships, and explain its action.

11. Describe a form of evaporator or double distiller. Sketch in the direction of flow of water and steam.

12. Describe any method of inducing a draught up the funnel. What are the advantages of induced draught over the closed stokehold system.

13. Describe how an asbestos packed cock is repacked. Sketch one so fitted.

14. Describe and show by sketches the means adopted to produce circulation in (1) Water tube boilers, (2) Circular return tube boiler How is the water circulated in a Yarrow water tube boiler.

15. Sketch a steam bilge ejector and describe its action.

16. Describe the usual system of bunker ventilation. Show by sketches the direction of the ventilation supply and exhaust.

17. Explain what is meant by the terms external and internal work done during evaporation of water. Show that the external work is nearly the same at all pressures, and explain why high pressure steam may be used with more economy than low pressure steam.

18. Distinguish between saturated and superheated steam. What per-centage of water is carried in suspension by steam which has had 1,100 British thermal units expended per pound in its production at temperature 347° F., from water at 102° F. ?

19. State the relation which exists between the three quantities—
Heat expended in the production of steam ;
Heat rejected by the steam into the condenser ; and
Work done by the steam in the engine.

If 20 pounds of steam are used per hour per horse power, each pound of which requires 1,100 B.T.U., for its formation, how many thermal units are carried away per second by the condensation water, and what is the efficiency of the steam in the engine ?

20. When steam expands in a cylinder, describe how the pressure varies with the increase of volume. Point out the distinction between this, and the expansion of a gas by Boyle's law, and describe the variation of temperature which a steam cylinder undergoes in the double stroke.

21. Describe how, by means of an indicator diagram, an estimation may be made of the consumption of steam in an engine, and explain why, when the steam is much expanded, the actual consumption must exceed this estimated amount.

22. Explain why the total ratio of expansion in a compound engine is independent of the point of cut off in the low pressure cylinder, and explain also, why the total power of the compound engine is, within moderate limits, independent of the size of the high pressure cylinder.

23. State an expression for the efficiency of a thermally perfect heat engine. If an engine, working between the limits of temperature 400° F., and 100° F., requires an expenditure of 200 B.T.U., per minute per horse power, determine the relative efficiency.

24. What are the chief constituents of coal which give it its value as a heat-producer ? Describe the important chemical actions which take place during the combustion of coal, and obtain an expression for the calorific value of coal containing given quantities of C, H and O.

25. Describe the combustion of coal, so as to explain the formation of smoke and flame.

26. Explain the action of a chimney, or funnel in inducing a draught. State approximately the quantity of air required per pound of coal burnt, and mention the nature of the losses which occur—first, when the supply of air is too limited; second, when it is too great.

27. Estimate the temperature of the gases passing from a furnace when coal capable of yielding 14,000 B.T.U., per lb., is burnt with 19 lbs., of air, supplied at a temperature of 75° F., supposing half the heat of combustion to be radiated to the furnace sides and crown.

28. Show graphically the effect of clearance on the economy of the engine. How can economy be gained in compound engines when the clearance is large.

29. Assuming that the I.H.P., varies as the cube of the speed; how much coal would a ship consume when the engines are indicating 3000 I.H.P., the consumption being 2·2 lbs., per I.H.P., if at 10 knots the total consumption is 2 cwt. and 3·0 lbs., per I.H.P.?

30. Sketch and describe a stern shaft coupling and the method of examining the stern shaft and tube.

31. Sketch and describe a cylindrical slide valve. If the valve takes steam on the inside, would the cut-off be later or earlier when the eccentric is advanced. What effect would this have on the lead of the valve?

32. Describe fully a set of triple expansion engines suitable for a large armourclad, and state the advantages you would expect to obtain from using such a type of engine.

33. State the steam pressure you would use, and describe, with outline sketches, the form of boiler you would employ with the above engines.

34. Explain fully the advantages of fitting vessels with closed stoke-holds, and state the parts of the machinery and boilers which you consider would require special attention when the forced draught is being used.

35. What increase of power would you expect to obtain from a set of boilers fitted with the forced draught as compared with the same set under natural draught.

36. Describe briefly the means that have been adopted to reduce the weights of machinery of modern vessels.

37. Show, by sketches, how you arrange the framing for a set of vertical engines.

Of what material should the framing be made?

38. Describe a form of valve gear by which the necessary operations of the slide valve are obtained without the aid of the link motion.

39. Sketch and explain the indicator diagrams you would expect to obtain from a set of triple expansion engines with three cylinders.

40. Describe how you would estimate the consumption of steam from the indicator diagrams of a compound engine. Explain why the actual amount generally exceeds the estimated quantity.

41. Describe the pumping engines and fittings provided in war vessels for use in case of fire.

42. Explain fully the action of the screw propeller, and show that for the propeller to be efficient, slip is necessary.

43. Describe fully the manufacture of a propeller suitable for a torpedo boat, stating, with reasons, of what material it is made, show, by sketches, the method of attaching the blades to the boss.

44. Enumerate the principal causes of loss of efficiency with the ordinary screw propeller.

45. Describe the screw turbine propeller, and state the advantages you would expect to obtain from it as compared with other propellers.

For what class of vessel is the screw turbine propeller specially suitable?

46. What is the most suitable position for a screw propeller in a vessel? Give your reasons, and state the objections to placing the propeller in the bow.

47. Sketch and describe some means of reducing the work on the link motion when the slide valve is heavy.

48. Sketch and describe a method of reducing the pressure of the slide valve on the cylinder face.

49. Sketch and describe a feed water filter and describe a method of cleaning it when under steam.

50. What is the use of a feed water heater?

Can it be fitted so that no economy is gained?

Describe where you would place it and the steam and water connections.

51. Sketch and describe how the pistons are made steam tight in the cylinders. What is the use of a junk ring? How do you line up a piston in horizontal engines

52. The engines of a ship, when working at full power, develop 4,000 I.H.P., the speed of the ship being 14 knots, and the consumption of coal 2·5 lbs. per I.H. . per hour. At this speed, the ship could steam 3,000 knots; determine her speed when developing 3,000 I.H.P, and the distance she could steam at this speed, the consumption of coal then being 2 lbs. per I.H.P. per hour.

53. Mention some of the principal causes of corrosion in marine boilers and state what means are at present employed for its prevention.

54. In fitting zinc protectors to a boiler, what precautions are necessary to ensure their being efficient?

55. What is the use of a feed tank in an engine-room, and why are the feed pumps worked by auxiliary engines, instead of being worked off the main engines?

56. Mention the various mountings on a boiler, and their uses.

57. Describe the several fittings on the engines and boilers for obviating the effects of priming.

58. A set of four boilers placed back to back are required for a ship. Show, by an outline sketch, the general arrangement of boilers, smoke-boxes, uptakes and funnel.

59. State the various valves and cocks on the engines and boilers, that it is necessary to open, before getting underweigh.

60. Sketch a stern tube and shafting, and explain how the thrust can be taken of the ship.

61. Describe fully the method of adjusting a pair of crank head brasses.

62. State the difficulties that may occur in starting engines, and describe the fittings provided for assisting the manipulation of the engines.

63. What are the principal points respecting the working of the slide valve that can be determined from an indicator diagram? State why the vacuum shown by the diagram generally differs from that shown by the gauge on the condenser; and state what you would expect this difference to be in a well-designed engine.

64. Describe fully the arrangements in an engine-room for pumping out the bilges.

65. Show, by means of sketches how the liner is attached to a cylinder and how made steam-tight at both ends.

66. Describe some means of working expansively in either cylinder of a set of engines by linking up, without the aid of a separate expansion valve.

67. Show how the mean pressure is obtained from an actual indicator diagram, and state what data are necessary for ascertaining the Indicated Horse Power.

68. State what parts of engines and boilers are now usually made of steel, and give reasons why steel has been so largely introduced.

69. Show, by sketches, how you would stay the combustion chambers of a flame-tube boiler, and the method employed in attaching the longitudinal stays in the steam space to the ends of the boiler.

70. Describe how the bearers for carrying the boilers are fitted in an iron ship, and how the boilers are secured in their places.

71. Sketch a safety valve for a high-pressure boiler, showing in detail the lifting gear.

What amount of lift should be given to the valve?

72. Describe fully the construction of a surface condenser, stating the materials of which it is made.

73. Show, by the aid of a sketch, the way in which the cylinders of a set of vertical inverted engines are carried.

74. Make an outline sketch of a steam starting engine, and the gear connecting it to the link motion.

75. The engines of a ship make 105 revolutions per minute, the speed of the ship is 14 knots, and the pitch of the propeller 14 feet. Find the slip per cent.

76. Each screw is driven by a set of vertical engines, developing a maximum power of 3,750 horses. The length of stroke is 3 feet 6 inches, number of revolutions 110 per minute, and steam pressure by gauge 160 lbs. per square inch.

State the description of engines, and ratio of cylinder volumes you would employ, and calculate the diameters of the cylinders.

77. State the number and description of boilers that should be used, and sketch one of the boilers, showing clearly the staying of the various parts, and marking the principal dimensions.

78. State the kinds of rivetting that should be employed for the various joints, and design the longitudinal joint for the shell plates.

79. Calculate the thickness of the shell plates. The ultimate strength of the steel plate may be taken as 26 tons per square inch, and the efficiency of the longitudinal joint 75 per cent.

80. Calculate the area of funnel required, and draw an outline sketch, showing the arrangement of uptakes, funnel, and ventilation casings.

81. Draw the slide valve diagram for the low-pressure cylinder, and enumerate the results obtained from a diagram. The cut-off may be taken at $\frac{7}{10}$ths the stroke, inside lap zero, and lead $= \frac{1}{6}$th the maximum opening to steam

82. Sketch a valve and cylinder ports, giving dimensions roughly.

83. Sketch a steel piston and rod for the high-pressure cylinder.

84. Sketch the condenser and air pump that should be employed, and find the cooling surface and air-pump volume required, supposing that no jet injection is fitted.

85. Calculate the required areas of inlet and outlet orifices for the circulating water, and state on what assumptions your calculations are based.

86. The speed of the vessel is 16 knots; find the diameter, pitch, and blade area necessary for each propeller, and state the range of pitch that should be allowed.

87. A boiler is filled with 10 tons of fresh water to working height and after a few days the density rises to 4; how much salt water has been used?

88. Name all the cocks and valves on a boiler and state their uses.

89. When raising steam; what valves would you open, starting at the boilers and ending with the sea connections? When would you start the circulating pumps?

90. What is the use of an evaporator, and what advantage has it over the simple distiller.

91. Give the causes for making salt water with an evaporator. Why does the evaporator sometimes prime?

92. From what depth will a pump draw water? Is there any limit? Why?

93. Describe the action of a separator.

94. Describe an oil cup with a siphon worsted. How far down the tube should the worsted extend.

95. What precautions are necessary in cold climates, when the temperature is below freezing point?

96. With a vertical inverted triple expansion engine there is a liner about half an inch thick between the ahead eccentric rod and the strap, and in Examining the Engine this piece is lost and forgotten; what difference will its omission make in the working of the Engine and its economy. (1). If omitted in the high pressure eccentric strap which works a piston valve taking steam in the centre? (2). If omitted from the low pressure eccentric strap which works a common double ported valve?

97. In the last question, show by a rough diagram the effect on the indicator diagrams?

98. In direct acting vertical inverted engine show where the greatest pressure is exerted on the guide bars and its direction for both up and down strokes.

99. Which is *convection*, which is *radiation* and which is *conduction* in the following cases :—(1). Heat from the fuel to the furnace crown. (2). Heat passing from one side of the furnace crown to the other. (3). Heat passing from the steam pipes in the engine room. (4). Heat of evaporation ?

100. What is the measure of a horsepower ? How is indicated horsepower ascertained ?

101. What is *cushioning* or *compression* in a steam cylinder ? How is it affected by the amount of lap or minus lap there may be upon the exhaust ? How is it affected by the exhaust pressure ? When does cushioning become a total loss of work ?

102. What is meant by circulation in a boiler, and what are the results of defective circulation ?

103. Flame sometimes seen at the top of the funnel ; what causes this appearance ; Is it beneficial or detrimental ? Why so ?

104. Of what does the boiler scale consist ? Where is it most objectionable ? How is it removed ? How is its formation prevented ? What evil effects are produced by it ?

105. What is the difference between a bucket air pump, a piston air pump and a plunger air pump ?

106. What is a compound engine ? What different kinds are there for screw steamers, in respect to the number and arrangement of their cranks and cylinders ? Describe a triple expansion engine.

107. Sketch and describe some form of link motion or valve motion.

108. What are the practical guides to the proper opening of the inlet valve for the circulating pump ?

109. Describe an air pump bucket with its valves and packing and show how it is worked. Of what are the valves generally made ?

110. What is meant by the "*pitch*" of a screw propeller ? How is it measured ?

111. Why is soda sometimes put in a boiler, and how is it put in under weigh ? What is the kind of soda used ?

112. What are the necessary fittings of a marine boiler ? What are their uses ?

113. Through what cocks or valves, pipes and chambers does the circulating water of a surface condenser pass ?

114. About how much fuel per indicated horse-power per hour is required by (1) a Common engine, (2) Compound engine, (3) Triple expansion engine, (4) Quadruple expansion engine.

115. What is the ecomony effected by using a surface condenser?

INDEX.

PAGE.

Air blast 48
— compressing machinery 166
— locks 49
— pipes on hotwells ... 99, 192
— pressure or vacuum gauge 70
— pump ... 97, 98, 101, 206
— — auxiliary ... 179
— — valves 102
— required for combustion 43, 44
— thermometer, absolute zero 45, 84
Area of funnel 73
— — pistons 88
— — propeller 220
— — safety valves ... 52
— — steam ports 136
— — through valves ... 52, 56
Armour gratings 71
Artificial draught ... 46
Asbestos packed cocks ... 67
Ashes 74
Ash hoist 71, 166
— pit water service ... 76
— shoots for closed stokeholds 71
Automatic feed of boilers 58, 171
Auxiliary condenser ... 179, 193
— engines (general) ... 166
— exhaust pipes ... 94
— starting valves ... 116
— steam service ... 57
— or winch condenser ... 193

Babbitt metal 129
Balance cylinders for slide valves 137
Balancing engines ... 88
Banking fires 77
Bar links 145
Bilge ejector 233
— injection 103
— pumps ... 174, 232
— suctions on circulating pumps 103
Blowing down, loss from ... 53
Blow down cock ... 66, 187
— — byepass ... 187

PAGE.

Boat hoists 166, 174
Boilers, care and maintenance... 74
— change of water in 80
— circulation of water 22, 68, 78
— comparative weights of 39
— composition of scale in 81
— cylindrical ... 12
— direct tube 17
— double ended ... 16
— evaporative efficiency 16
— locomotive ... 17
— low pressure ... 11
— mountings ... 51
— performance of ... 39, 239
— rectangular ... 11
— return tube ... 17
— stays 13, 19
— tubes 17, 23
— water tube, Babcock and Willcox 28
— — Belleville ... 34
— — Blechynden 30, 229
— — Fleming and Ferguson 38
— — Normand 23
— — Reed ... 37
— — Thornycroft — "Speedy" 21
— — — "Daring" 24
— — — water-bar 27
— — White ... 32, 33
— — Yarrow 35
Boiling point 4
,, ,, sea water ... 53
Brine cocks or valves 67, 187
British Thermal unit ... 8
Bulkhead valves ... 93, 231

Capstan engine ... 166, 174
Centrifugal lubrication ... 124
— pumps ... 103
Circulating inlet and outlet valves 96
— pumps 102, 179
— water, quantity of 104

PAGE

Clearance (in cylinders) ... 161
Closed ash pits 49
— engines 173
— stokeholds ... 49
Coal, composition of 41
— consumption of ... 40, 169
— — curves ... 213
— — per square foot of grate 20, 45
— evaporative power ... 43
Combustion 41, 42
— air required for ... 44
— chamber ... 13, 16
— forced, rate of 20, 45
— spontaneous ... 42
— total heat of ... 43
Compound engines 89
— — proportion of 92
— gauges — 61
Compression or cushioning 153, 158, 162
Condenser 96
— auxiliary or winch 179, 193
— — atmospheric exhaust 179
— tubes, fitting ends of 98
— water required for 104
Conduction of heat .. 46
— rate of 16, 183
Connecting rod (general) . . 120, 205
Copper tubes 23, 37
Couplings for stern shafting 127
Crank shaft 124
Cranks, angles of .. 88
Crosshead, piston rod ... 119
Curve, adiabatic or hyperbolic 148
— coal consumption ... 213
— crank effort .. 123
— indicated horse power 213
— — thrust ... 212
— of performance ... 214
— speed 214
Cushioning 153, 162
Cylinder 108
— clearance ... 161
— clothing 110
— constants ... 160
— drains ... 114, 204
— escape valves .. 114
— face 110
— jacket ... 109, 204
— liner 108
— ports and passages 109, 161
— relief or safety valves 114
Cylinders, arrangement of . . 88

Definitions and units ... 6
Density 5
— of boiler water ... 79
— sea water ... 53
— water in evaporators 188

PAGE

Diagrams, (see *Indicator*) ...
Zeuner's ... 134
— — when linked up 146
Differential or reversing valve 174
Distilling apparatus ... 200
— condenser ... 199
Drain cocks 114, 204
Draught, artificial ... 46, 225
— chimney 46
— induced ... 48, 225
Duplex pumps 171

Eccentric, angular advance of 133, 158
— position of ... 133
— rod 132
— rods, crossed or open 146
Economy of evaporators ... 188
— expansive working 148, 209
— fuel 75
— steam jacket 72, 85, 90
Efficiency 7, 84
— boiler ... 16, 43
— evaporator ... 201
— heating surface ... 81
Electric generating engines ... 167
Energy 7
Engines, arrangement of cylinders 88
— balancing .. 88
— compound 90
— direct acting ... 87
— losses in 104
— oscillating ... 86
— quadruple expansion 90
— range of temperature in 85, 90
— return connecting rod 86
— triple expansion ... 89, 91
— trunk 86
— vertical 87
Evaporation of water ... 1
— total heat of ... 9
Evaporative efficiency ... 43
— power of coal ... 17, 43
— — liquid fuel 50
— tests of water-tube boilers 239
Evaporators 180
— brining down ... 188, 192
— double effect or multiple 196, 201
— economical production of water 188, 201
— Kirkaldy 185
— Maudslay ... 185
— Morison ... 185, 186
— Rayner ... 185
— Weir ... 182, 196
— working of ... 184
Expansion 147
— in compound engines 148

	PAGE.
Feed pumps	169
— — automatic control	171
— tanks	171
Feed valves ...	57
— water filter	201
— — quantity of	181
— water heaters, Morison	191, 199
— — — Normand	198, 199
— — — Worthington	196, 199
Ferrules for condenser tubes	98
Fire engines and pumps	174, 232
— grate area of ...	46
— — construction	77
Flooding valves	234
Foot pound	6
Force	6
Forced draught ...	46, 225
Formation of scale ...	22
Framing of engines	92
Funnel, area	73
— cover	73
— draught	45
— stays	73
— telescopic ...	73
— temperatures	45
— uptake to ...	73
Furnaces	14
— Adamson ring ...	14
— analysis of scale ...	81
— corrugated ...	13
— locomotive boiler ...	19
— water tube boilers	23
Galloway tubes	19
Gauge, air pressure or vacuum	70
— compound or combined	60
— pressure	10, 59
— water ...	63, 65
— — position of lamp for	65
Gauge, vacuum	10, 62
Geddes' water drainer ...	194
Glands, packing	112
— screwing up gear for	113
Glass protector for water gauges	65
Governors	115
Grate surface ...	20, 30, 38
Gudgeons, guides and blocks	119
Heat, communication of .	13
— latent	9
— loss from blowing down	55
— mechanical equivalent	8
— sensible	9
— total of evaporation	9
Heating surface	183
Horse power, indicated	160
— — nominal ...	160
Hydraulic machinery	166
Hydrokineter	68
Hydrometer ...	52
Indicated horse power ...	7
— — calculation of	159
— — curve of	213
— — per ft. of grate	38
— — per ton weight	39
— thrust ..	211
— — curve of	212
Indicator	151
— cocks	151, 152
— diagrams	153
— — combined or compounded	164
— — loop in	163, 209
— — measurement	159
— faults shewn by use of	153, 157
— friction or undulation	158
Induced draught	46, 225
Initial friction of engines	213
Internal feed pipes ...	57
— steam pipes ...	56
Jacket steam	85, 109
Jet injection air pump ...	97
— — condenser ...	98
— — feed water heaters	191
— propulsion ..	216
Joule's equivalent	8
Joy's valve gear ...	140
Junk ring for piston ...	111
Latent heat	9, 11, 43
Lighting fires	77
Length, unit of ...	5
Lignum vitæ bearings ...	128
Liquid fuel	50
Link block	144
— motion	144, 145
Linking up, economy of	162, 163, 208
— effect of, shewn by valve diagram	145, 146, 209
Liquefaction	72
Lubrication, centrifugal ...	124
— external ...	208
— internal	72, 79, 82, 207
Main bearings	124, 205
— drain suctions ...	231
— engine framing ...	92
Make up feed	181
Mass	5
Mean pressure ...	149, 159
Mechanical equivalent of heat	8
Momentum balance cylinder	137
Multiple expansion ...	90
Multipliers, constant for I.H.P.	160

	PAGE.
Neck ring	113
Negative slip	219
Nominal horse power	160
Oscillating engines	86
Packing, back of slide valve	136, 137
— for rods	113
— metallic	113
— piston	111
— pump	169
Paddle wheel, feathering	214
— — overhung	215
— — propulsion	214
— — radial	214
Pass valves	116
Piston	110
— fittings	111
— leaky	155, 156
— junk ring	111, 206
— packing	111, 206
— rod	112
— —crosshead or gudgeon, guides and blocks	119
— —nuts and connections	112
— —packing and gland	113, 205
— slide valve	139
— springs	112, 206
Pitch of screw propellers,	218
— — — alteration of	223
— — — measurement of	221
Plummer block	125
Power	7
Pressure, absolute	34, 10 61
— and temperature	34, 10, 61
— and volume	2, 4
— effective	149
— gauges	60
— — air	70
— — compound	61
Priming	19, 74
Propeller, angle of	218
— blade area, disc area	220
— jet	216
— measurement of pitch	221
— race	210, 219
— screw	217
— shafting	127, 206
— slip of	219
— surface	220
— turbine	216
Properties of steam, table of	4
Pumping arrangements	230
Pumps, air	179
— centrifugal	103
— circulating	102, 179
— feed	15, 169
— fire and bilge	174
Quadruple expansion	90
Radius of action	169, 209
— of eccentricity	132
Raising steam	77, 204
Ramsbottom rings	112, 137
Rate of conduction	16, 45, 183
Ratio of cylinder volumes	92
— of expansion	162
Reducing valves	177
Regulating valves	114
Reversing gear	142
— valve	174
Safety valves	51
Salinometer	53
Screw propeller (*see* propeller)	217
Screwing up gear for glands	113
Sea connections	234
Sensible heat	9, 11
Shaft couplings	127, 209
Slide valve, balance cylinder	137
— — common	134
— — cylindrical or piston	139
— — diagrams, Zeuner's	134, 145
— — double ported	136
— — lap and lead	132, 133
— — incorrectly set	157
— — motion	131
— — normal	174
— — relief ring	136
— — setting	135
— — travel	136
Sluice valves	230
Smoke boxes	13
— prevention of	44
Specific gravity and volume	5
Speed curves	212
Spring buffer barrel	176
Starting gear	142
— valves	116
Steady pipe	62
Steam, admission of	134
— blast	48
— drain traps	194
— expansion of	147
— jackets	72
— pipes, arrangement of	93, 179
— regulating valves	114
— superheaters	72
— table of properties of	4
Steering gear and engines	175
— — buffer barrel for	177
Stern bracket	128
— coupling	127
— shaft and tube	127
Stoking	75
Stop valve	55

PAGE.

Stop valve bulkhead ... 94, 231
— — self closing ... 56
Superheated steam .. 9, 72
Supplementary feed cock 181
Surface blow out or brine 67, 187
— condensation ... 96
— feed water heaters ... 189

Talc water gauge ... 65
Tandem engines ... 90
Temperature, absolute ... 3, 45, 86
— of combustion 44
— of funnel gases 45
— of steam ... 4, 5, 8
— range in expansion engines 84, 90
Test cock 67
Thermal unit 8
Thornycroft boilers 21, 24, 27
Thrust block 126
— indicated ... 211
— — curves of 212
... of propeller ... 211
— rings and discs 126, 206
Triple expansion engines 92, 162
Turning engines 174, 179
— gear 179

Units 5

Vacuum gauge ... 61
Valve circles 134, 146
— gear 140
Velocity 6
Ventilation 73, 224
Vertical air pump 100
— engines ... 87
Volume 2, 4, 5

Waste heat, utilization of, in condenser 183
— — — funnel 45, 48, 191
Water evaporation per pound of coal 188
— gauge automatic shut off valve 64
— — glasses ... 65
— — glass protector 62, 66
— — position of lamp 65
— — Talc ... 66
— required for condenser 104
— — feed ... 181
— service for engines 92, 126, 208
— used per I.H.P. 43, 181
Water-tight bulkheads ... 227
— doors ... 229
Water tube boilers (*see* Boilers)
Weigh shaft 144
Weight of boilers per I.H.P. 39
White metal bearings 129, 145
Winch condenser 193
Wire drawing steam ... 34, 154
Work 6
— done during expansion 147
Worn bearings, to repair in place 129

Zeuner's diagram ... 134, 146
Zinc protectors ... 79, 128, 234

PRINTED & PUBLISHED BY J. GRIFFIN & CO., 2, THE HARD, PORTSMOUTH.

Supplement.

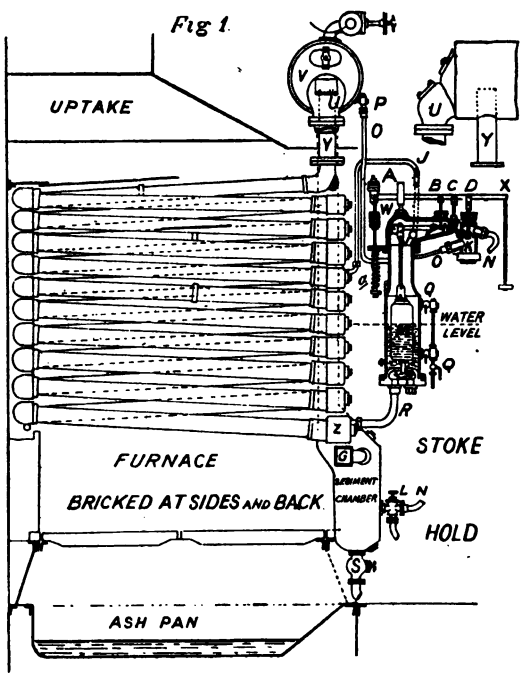
Reprinted from the Journal of the Royal United Service Institution.

THE CONSTRUCTION AND WORKING OF BELLEVILLE BOILERS.

BY A. E. TOMPKINS, CHIEF ENGINEER, R.N.

Belleville Boiler.—This boiler is built up of many tubes of about 4½ inches in diameter, and about 7 feet long. The tubes are arranged in groups called the *elements*, each boiler is composed of seven or eight elements, and each element contains eighteen or twenty tubes. From the sketch (Fig. 1) it will be seen that, commencing from the lowest junction box Z, the

Fig 1.



tubes are inclined upwards by raising opposite ends alternately. The junctions are formed at the ends of each two tubes, one of which is inclined downwards to the junction box below, and the other upwards to the junction box above. The lowest tube in each element is connected to the *feed collector* G, and the uppermost to the steam chest V by a pipe Y.

After filling the boiler to the working level shown, fires may be lighted. The steam and water then rise through the generating tubes until finally ejected into the steam chest V. From here the steam escapes through the steam valve or safety valves, and the water falls into the bottom of the chamber and mixes with the feed water pumped in by the feed pumps. This water flows downwards by the downcomers U to the sediment chamber. The upper part of the sediment chamber is connected to the feed collector G, so that a continuous flow of water is supplied to the generating tubes. The boiler is surrounded by a casing of thin sheet-iron and asbestos. At the front of the boiler there are two large doors which, (see also Fig. 14, Page 34,) when open, expose all the front junction boxes and fittings: these doors correspond to the smoke-box doors of the ordinary shell, or marine, boiler. Immediately below these doors are the furnace doors, generally four in number, and below these again are the draught doors leading to the ash-pits. The fires are forced to a small extent by introducing jets of air from just above the furnace doors on to the top of the fire. Special air compressing pumps are supplied for this purpose; the pressure in the jets is about 30 lbs. per square inch.

The Belleville boiler differs from nearly all other water-tube boilers in four important respects. 1. It has straight tubes of equal length and diameter. 2. Each tube can expand or contract almost independently of any other part of the boiler. 3. The flames strike the heating surfaces almost at right angles,

and this should give the best results, as it is most favourable to the generation of steam. 4. Each tube can be examined internally by removing the small door in the junction-box opposite the end of the tube.

In addition to these advantages, there are others of a practical character which affect its working in a satisfactory manner. The "circulation" of the water in the boiler is continuous, and constant in direction, this leaves the least deposit of scale; any loose scale or mud will generally find its way into the sediment chambers, and from there can be blown out by the valve S. Nearly the whole of the floor space occupied by the boiler can be used as grate surface. Its weight is not much below that of the ordinary marine boiler, but the advantage is greater than it otherwise would appear, if it be noted that in the Belleville only natural draught ($\frac{1}{2}$ inch air pressure) is required to produce greater power per unit of weight, compared to the forced draught (2 inches air pressure) of the ordinary boiler.

The weight of an eight-element boiler without mountings or water is about $14\frac{1}{2}$ tons, the weight of water at working height is about $1\frac{1}{4}$ tons giving a total of $15\frac{3}{4}$ tons when working. From 550 to 600 I.H.P. may be obtained from this boiler when burning 20 lbs. of coal per square foot of grate: a very low rate of combustion, and which can be easily obtained by good stoking without forced draught.

Automatic feed Regulator.—This is probably the most important factor in the successful practical working of the boiler. In Fig. 1, a sectional elevation of the apparatus is shown in connection with a side view or elevation of the boiler, thus showing the relative position of the various parts.

Standing out a little from the front, and generally a little to the right or left, is the *automatic feed regulator*, which consists of a cast steel chamber, in which a float M can

move either up or down. The upper part of this chamber is connected by a pipe J, led up to the height shown and down to a junction box of the nearest element; the junction box generally selected for the connection is the fourth from the top of the element. The bottom of the chamber is connected by the pipe R generally to the lowest junction box Z, but sometimes to the *feed collector* G or to the upper part of the sediment chamber. By these two pipe connections R and J a water level is obtained in the float chamber corresponding with that in the boiler. Consequently any alteration in this water level will operate on float M. This float is fitted with a guide rod which works in a bracket T. The float is also connected by a vertical rod EM to the lever EFH, which has its fulcrum at F; consequently any movement of the float operates on the rod BH, and by it on another lever ABCDX exterior to the chamber. The lever ABCDX has its fulcrum at C. A rod DK works the feed valve K. At A a small adjusting spring *a* and weights W and A are placed; these are used for any small adjustment of the proper working equilibrium of the float and levers. By adding weights it will be seen that the float may be allowed to rise more easily; while by removing them there is a greater tendency for it to fall.

Suppose the water level to be falling in the boiler, then the float M will fall with it; by means of the interior lever EFH the rod BH will rise and produce a fall in the rod DK, thus opening the valve K; this will admit the feed water from the pipe N into the pipe O and through this and the non-return valve P into the steam chest V.

A pressure considerably in excess of the working boiler pressure (nearly double) is maintained in the pipe N by the feed-pumps. The quantity of feed water can be regulated by the valve L, which for convenience is usually fixed to the sediment chamber, but has no internal connection with it. From the lower part of the steam chest the water finds its way

by the downcomers U (one of which is fitted at each end of the steam chest) to the sediment chamber; the upper part of which is connected to the feed collector G.

A water-gauge glass QQ and test cocks are generally fitted on the float chamber, which acts as a steady pipe for this purpose. Another gauge glass is fitted to a steady pipe at the other side of the boiler, the upper and lower parts being connected by pipes in a similar way to that in which the float chamber is connected to the boiler.

The lever EFH is pivoted on knife edges at F and is fitted with a roller bearing at H. All the packing glands of the lever rods are of special construction and are generally packed with graphite packing. The valve K can be examined by removing the screwed cap at the bottom of the valve box. At X a rod is fitted so that the valve and lever can be worked by hand from the stokehold platform.

Steam Chest or Separator.—The extremely small amount of water contained in water-tube boilers, compared with the enormous rate of evaporation, necessitates special means for separating the steam from the water from which it is formed, so as to prevent the latter finding its way with the steam into the engines. It might be mentioned here that the great gain in power per unit of weight of water-tube over the ordinary flame-tube boilers, is in a great degree due to this comparatively small weight of water contained at working height. In the Belleville boiler this gain is not so great as in some others, the Thornycroft for example; but, on the other hand, the power is obtained with a lower rate of combustion per square foot of grate surface. In Fig. 2, Y is the junction of an element to the steam chest V. When the boiler is at work, steam and water are ejected upwards from the generating tubes (or elements) and impinge on a series of dash plates with serrated edges, following the course of the arrow heads through slits or small holes in the plates, until finally

the steam passes through small holes (one of nine-sixteenths of an inch in diameter for each element) into a steam-tight chamber. The steam pipe leading to the reducing valve, and from thence to the engines, is connected by the usual steam valve to this chamber. The water separated from the steam by the *dash plates* flows down into the bottom of the steam chest and mixes with the feed water from the automatic feed regulator on its way through the downcomers at each end of of the steam chest to the sediment chamber and feed collector. From the sediment chamber and feed collector it circulates again through the generating tubes.

Where the junction of the element to the steam chest is fitted, a doubling plate is riveted inside the steam chest. Near the bottom of the steam chest towards the front are two or three small oval doors, which can be easily removed for cleaning and temporary examination of the interior. At each end in some instances, and at only one in others, a flanged joint is fitted, so that by removing the steam chest from its position on the boiler and taking off the cover, a thorough

Fig. 2

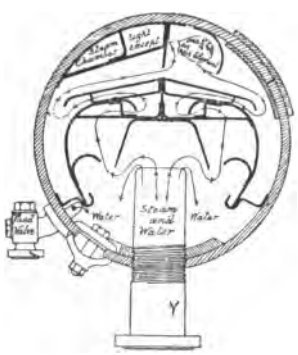
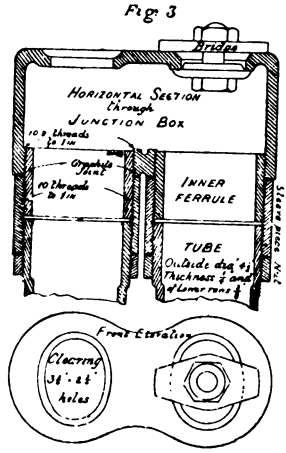


Fig. 3



examination or refit of the interior parts can be made. The

connection for the downcomer is generally cast on this cover. If there is only one cover, a small oval door is fitted at the opposite end above the downcomer (see Fig. 1).

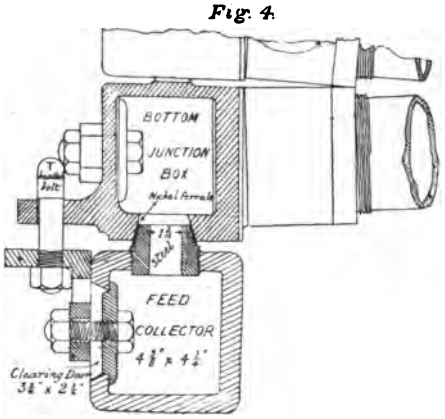
Junction Box.—Fig. 3 shows a horizontal section and front elevation of the ordinary junction box at the front end of the tubes. In the Belleville boiler it will be noticed that the usual English practice, of expanding the tube ends by rollers to make the joints steam-tight, is not carried out, but that screwed joints are generally employed. The junction box varies slightly in form and shape as made by different firms, but the principle is the same in all. There are two spigot pieces cast on it, which are screwed internally with a slightly different pitch of thread to that on the ferrules and sleeve pieces; the slight difference of pitch secures a tight joint. The sleeve pieces are made tight at each end by graphite joints and a nut at the outer end. A blunt chisel or set is used for hardening up the nuts and sleeve pieces where space does not allow of gas-tongs being used. Opposite the end of each tube is a small clearing hole fitted with an oval door secured by a single bolt and nut through a bridge piece. This door is surface jointed.

The junction box at the back end is very similar as regards the securing of the tubes, but the sleeve piece and ferrule are omitted and the tube is screwed directly into the junction box. No clearing holes are fitted at the back end. Lugs are cast top and bottom of each junction box to carry the weight of the tubes above. The lugs are side-slotted from front to back so that each junction box can move in the direction of the expansion of the tubes, independently of those next it. The front junction boxes in one row, generally the the second from the top, are fitted with a fusible plug, so that warning may be given and fires put out in case of any stagnation in the circulation and consequent overheating of an element.

Special junction boxes are required for the top and bottom connections at the front end. The top box is secured to the vertical tube Y, leading to the steam chest by a square flanged joint with four bolts and nuts.

The bottom connection shown in Fig. 4 is a sectional side elevation of the connection with feed collector. A horizontal section of the bottom junction box is very similar to that shown in Fig. 3, one of the differences being that one clearing door is omitted and a screwed plug substituted opposite the part where no tube is connected, there being only one tube con-

Fig. 4.



nected to each *front* bottom junction box. The lower water connections of the steady pipe and float chamber are generally made at this point. The lower part of the junction box has a conical hole drilled in it vertically which fits over a corresponding steel plug with a nickel ferrule facing for making the joint. This plug is screwed into the top of the feed collector, and forms the connection between it and the generating tubes. In front of the bottom junction box a lug is cast, so that it is secured by means of a T-headed bolt to an angle iron bolted on to the front of the feed collectors.

The feed collector has three or five clearing holes and doors fitted of a similar size and shape as those fitted to the junction boxes. At each end the feed collector is connected by a cast steel pipe to the upper part of the sediment chamber.

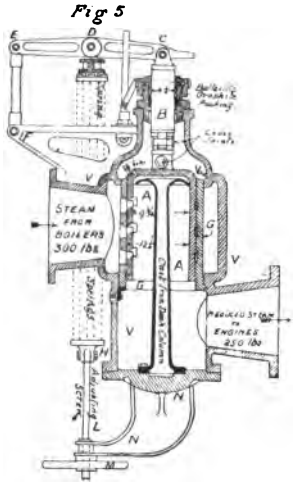
When two downcomers are fitted, there is a possibility of the water circulating unevenly; and to assist in dividing the circulation evenly, a flap valve is fitted in the top of each sediment chamber to control the flow of water into the feed collector.

Reducing Valve.—To reduce priming and the chances of its occurring, it is found advisable to fit a reducing valve in conjunction with Belleville boilers. The valve may be fitted at any place in the steam pipe, either at the boiler or at the engine. The latter has been adopted generally for naval boilers and a large reducing valve is now found in each engine room. The effect of reducing the pressure of the steam is to produce a better quality of steam, as by lowering the pressure (and temperature), a certain amount of heat is set free which converts some of the particles of water in suspension into steam. It also partly counteracts any condensation which may take place through imperfectly lagged steam pipes. If the steam generated by the boiler were dry *saturated* steam, the effect of reducing the pressure would be to *superheat* the the steam; within moderate limits this is not a probable effect, as nearly all *common* steam contains some priming water or particles of water in suspension.

A sectional elevation of a reducing valve is shown in Fig. 5. There is a cylindrical gridiron valve A, which has ports cut in planes at right angles to the axis and extending about two-thirds of the circumference. This valve is open at the bottom end and partially closed at the top, a few holes only being drilled to allow the reduced pressure access to the space above the valve. These holes are $\frac{5}{8}$ inch in diameter. The valve A is connected by two loose pin joints to a spindle B,

which is connected to the lever CDE at C; this lever has its fulcrum at E. Similar ports are cut in a cylindrical valve face G which surrounds the vavle, and which is secured into the valve chest V in a similar manner to that of the liner

Fig 5



of a cylindrical slide valve into the slide casing. The lever CDE has a cross beam at D, poised on knife-edges, to which are attached frames containing several springs; the lower part of the frame is attached by a similar cross beam H to a square threaded adjusting screw L which passes through the boss of a wheel M working in a bracket on the bottom cover N of the valve chest By means of the wheel M the tension of the springs can be adjusted. The end E of the lever CDE is connected to a support on the valve chest by a rod EF.

In the figure the valve is shown *open*, the ports of the valve being opposite those in the valve face. Steam enters from the steam pipe as indicated, and finds its way through the ports into the interior of the valve, impinging on the cast-iron *dash column* as it does so.

The valve is in equilibrium when the tension on the springs is balanced by the upward pressure on the valve. The difference in the area acted on by the reduced steam pressure above and below the valve, is the area of the spindle B, the upper part of which is open to the atmosphere. From this it will be seen that if the pressure exceeds that for which the springs are adjusted, the valve will rise, and consequently tend to close itself. By careful adjustment, when the flow of steam is fairly constant through the valve there it very slight movement or oscillation. As there are no packing rings round the valve, there is a small leakage at all times, and particularly when the engines are stopped; consequently, it is convenient to have a small safety valve on the *reduced* steam pipe to take away any excess of pressure over that required. A small drain pipe connected to an automatic steam drain trap is also generally fitted to take away any water from the lower part of the steam chest.

By adding more springs to the frame, or by using the adjusting screw to put on more tension in the springs, the reduced pressure would be increased; and *vice versa.*

Economisers.—In conjunction with new naval boilers, economisers, a type of feed heater, are to be fitted. They consist of sets of tubes, placed in the uptakes to the funnel, through which the feed water passes on its way to the boiler. This is a method of utilising some of the heat which would otherwise be wasted up the funnel. They are still in their infancy, but their utility is so evident that an economy of 20 per cent. gained by their application would not be astonishing. The uptake is the natural position for a feed heater theoretically, and any practical or mechanical objections should soon be overcome. The arrangement of the tubes and junction boxes of the Belleville economiser is very similar to the boiler, but, of course, smaller.

The Belleville boiler (without economiser) has up to the present shown no particular economy of coal over the ordinary boiler; this is due principally to inexperienced stoking. After the stokers have become accustomed to the large furnaces, enormous economy is gained. I have been constantly reminded of this during the past two years in training stokers with Thornycroft boilers, the facilities for stoking which are very similar to those in the Belleville. After a few days' practice, the same men have been able to obtain nearly double the H.P. with the same speed of fan and air pressure; this is, of course, more noticable at moderate powers; at very high powers for short periods it is not so remarkable, but is still evident. The Belleville boiler is a very easy boiler to fire indifferently, but experience is absolutely necessary for economy.

Apart from all considerations of space, weight, and economy, it is in all its essential points an engineer's boiler, as it meets his requirement for facility of examination of all parts, both internally and externally. The comparatively moderate rate of combustion also appeals to the sea-going engineer; as he knows that he can get within reasonable limits of the maximum power for as long as required, and also with safety. As further experience is gained, better results will be obtained, and further improvements will be made, and eventually economy must follow.

Yarrow Boiler.—Fig. 15a. shews a general view of the Yarrow Boiler with the casings removed. Fig. 15b. gives a front view in part section, the air for the fires is admitted through the Light hinged doors, marked, and after passing outside the boiler, enters the ashpit at the back end. This boiler is slightly modified since the description given on page 35 was written, and it will be noticed that the manhole cover

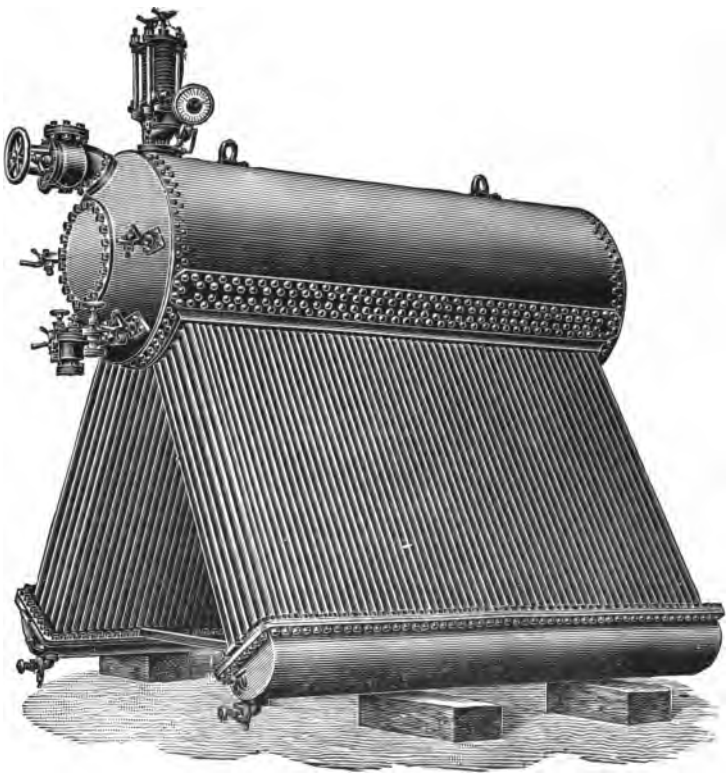


Fig. 15a.

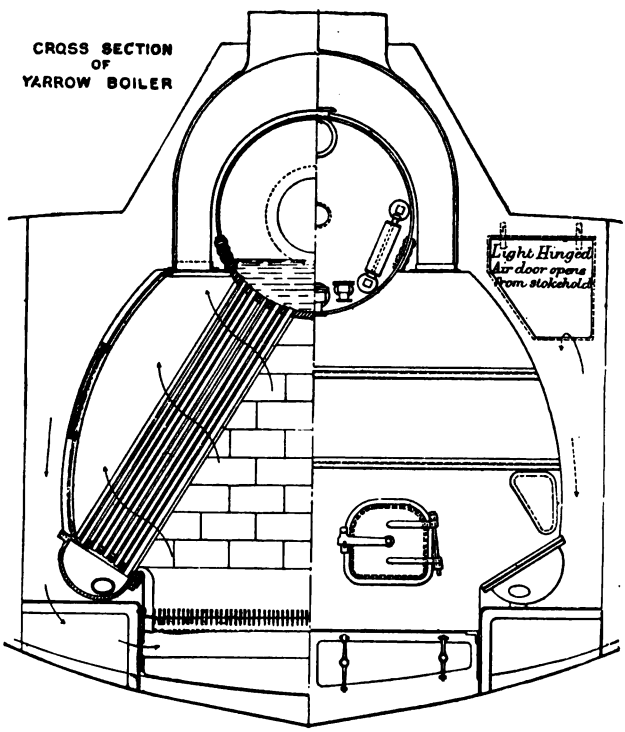


Fig. 15b.

on the top chamber is not now encumbered with boiler mountings. It is constructed throughout of steel, including the tubes.

SURFACE CONDENSER AND FITTINGS.

(To replace description on page 97.)

IN figure 46a, H is the surface condenser, which is generally of cylindrical form as shown in figure, the tubes are horizontal and run from end to end of the condenser body, and have a length of from 6 to 8ft. The circulating water, which enters from the sea by the sea suction valve, and inlet valve D, passes through a pipe E, into the pump F, and is forced by the pump

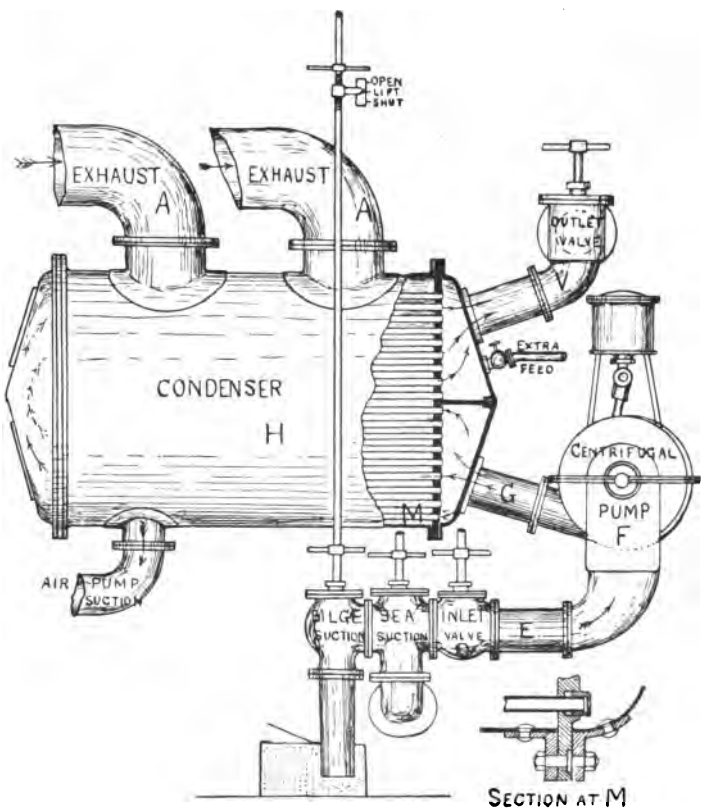


Fig. 46a.

through the pipe G into the space at the end of the condenser between the tube plate and the cover. From here the water passes through the lower tubes to the back end of the condenser, and from there back through the upper tubes to the front end, and goes overboard through the pipe V, and the outlet valve. The direction of the circulation of the water is shown by the arrows. It will be noticed that the cover at the front end has a dividing plate so that the water cannot find its way to the outlet until it has passed through the tubes. In some instances it is found convenient to make the condenser smaller in diameter and consequently it is then made longer; in this case the outlet is at the back end, and no dividing plate is necessary. In the sketch a valve is shown near the *sea suction* called the *bilge suction valve*: this is an emergency valve, and is fitted so that the circulating pumps in addition to their proper functions can be used to pump out the engine rooms. This valve can be worked generally from a good height above the floor, and generally rather above the level of the water outside the ship. The sea suction and inlet valves are fitted in a similar manner. Frequently in shallow draught ships, a *weed trap* is fitted at E, so that by removing a manhole cover any weed that may have caught in the grating may be cleared. The weed trap is simply a movable grating fitting in a slot across the orifice of the pipe. In torpedo boat destroyers it is a common practice to clear the weed traps immediately before, or while raising steam. The weed trap prevents any obstruction finding its way into the pump chamber or condenser tubes. Small manhole covers are fitted in the large covers of the condenser, so that the tube plates and tubes can be readily examined. It is usual to fit zinc plates at these parts, and a common practice is to attach them to the manhole covers themselves. Care must be exercised when this is done that the zinc plates are not insulated by the jointing material, and are in metallic contact with the body of the condenser. A piece of zinc should also be attached to the

grating in the weed trap. The condenser body is built of thin brass sheeting, strengthened by angle ribs circumferentially if required. The tube plates are jointed to the condenser body as shown in the small sketch, *section at M*, and it will be noticed that the large covers can be removed without disturbing the joint between the tube plates, and the condenser body. A small pipe marked *extra feed* is fitted with a valve so that a small quantity of water can be admitted from the sea to the fresh water side of the tubes to make up any losses which take place. With water-tube boilers this valve is only used in great emergencies, that is, when all sources of fresh water feed are exhausted, and the evaporatoring plant cannot supply the deficiency.

The steam enters the condenser by the eduction or exhaust pipes A, A and dribbles between the tubes, becoming condensed during the passage, and finally leaves by the *air pump suction* pipe at the bottom of the condenser. When the feed tank is below the level of the condenser; a non-return valve is fitted in the pipe connecting the bottom of the condenser (sometimes termed the *hot-well*) with the feed tank; when the air pump is not working, the water then gravitates into the feed tank. This plan is not always possible, and in this case a separate suction pipe is fitted to the *feed* or other pumps by using which the hot-well can be kept clear of water. A water guage glass is sometimes fitted to the lower part of condenser to indicate the amount of water in the hot-well.

PRIMING IN WATER-TUBE BOILERS.

THE introduction of water-tube boilers has again brought into prominence the evils of priming. Priming is said to take place when water in suspension is carried off by the steam in its passage from the boiler. The steam is actually surcharged with watery vapour and the mixture is sometimes called *surcharged* or *humid* steam. Several causes are assigned for priming taking place but so far as I am aware, no one has successfully overcome its evil effects or provided an efficient remedy; probably the trouble lies in the diversity of causes and the many types of boiler, each of which has its own peculiarity. The principle known causes of priming are:—

1. Bad circulation of water in the boiler.
2. Contracted steam space.
3. Contracted water surface area.
4. Sudden increases of power developed by the engines, which are not immediately compensated by the boiler.
5. Irregular working.
6. Condition of the heating surfaces.
7. Salt or impure water and loose scale forming a mechanical mixture.

It may be interesting to quote here the experiences of over forty years ago.

*"One cause of *priming* on first starting the engines arises from the pressure being taken off the surface of the water in the boiler, and thus enabling the ebullition to go on with greater violence; but this is not the principal cause: the

* "The Marine Steam Engine" by Thomas J. Main, F.R.A.S., and Thomas Brown, Chief Engineer, R.N. (Third Edition, 1855.)

chief reason is, that many foreign substances become mechanically mixed with the water; for instance in getting up the steam in a muddy river, such as the Thames, the mud will, by boiling, be driven up to the surface of the water, and accumulating there, will prevent the free course of steam to the steam-chest, and consequently it forces up the water and mud before it. If there be any mucilage in the water, priming will also take place. .....There are few persons who have not noticed this fact one way or another. The cook well knows the tendency a vessel containing other substances besides water has to boil over at first; and in making coffee the case is remarkably exemplified, the whole mass will be observed to rise to the surface of the coffee-pot when beginning to boil; but after some time these effects are not so remarkable.....A boiler will likewise prime as the vessel goes out of salt water into fresh, and also in going out of fresh water into the salt: the first of these cases can be accounted for by the fact that fresh water boils at a lower temperature than salt water, and therefore, as the fresh water enters the boiler previously heated, the ebullition is more violent; but the contrary case is more difficult to explain; and indeed, this latter instance would almost lead one to suppose the former explanation not to be the true one."

It should perhaps be pointed out that at the time this was written, boilers were supplied with water almost directly from the water surrounding the vessel; and although this is not so now, the experience quoted throws some light on a subject which has never yet been clearly explained and which is still fought on purely mechanical lines. Something is wanted, which will enable us to work a water-tube boiler at all times with water, approximately clean and *partially* salt, without dangerous consequences from priming. *Common* steam frequently contains as much as 30 per cent. by weight of priming water and this may be taken as the safety limit, any higher percentage being dangerous.

Priming in any quantity is a loss of economy although it may not be perceptible or dangerous. (See also page 72.)

1. **Bad circulation of water in the boiler.**—The only remedy for this is to promote a good circulation by proper design of the boiler or by artificial means such as the hydrokineter. The circulation should be continuous and a downward current should be provided for, so that on all occasions the direction should be maintained at all points. We find this in most of the water-tube boilers of the "express" or small-tube type and also in the Belleville boiler. In flame tube boilers it is difficult to arrange for a distinct circulation, generally it is made by dividing the combustion chamber into many parts so that each furnace has its own particular combustion chamber. Between these combustion chambers is a *water space* leading up from the bottom of the boiler. The sub-division of large combustion chambers by brickwork is useless in this connection, and is of doubtful utility at any time. Bad circulation is not so marked in flame tube boilers as in water-tube boilers; this is due to the much greater quantity of water in the boiler and larger surface area from which the same quantity of steam is generated.

2. **Contracted steam space.**—This is the volume of the boiler internally above the water level, and can only be increased by increasing the size of this part of the boiler. The effect is however minimised by using a higher boiler pressure than engine pressure by wire-drawing the steam; a reducing valve is now generally fitted in connection with the Belleville and some other boilers.

3. **Contracted water surface area.**—The quantity of steam which can escape from a given surface, without carrying off an undue amount of priming water, must be some tangible amount, and there appears to be no difficulty in its determin-

ation by experiment. This quantity varies with the condition of the water used; it is greatest with clean fresh water and probably least with a mixture of fresh and salt water. The various types of screen and separator plates fitted in the steam space of some water-tube boilers are really an artificial method of increasing the otherwise restricted water surface areas. The surface area in the Belleville boiler might be increased to ensure greater economy; the separator plates might also be improved, and with the exception of the upper part which takes the place of an internal steam pipe, they are of doubtful utility.

4. **Sudden increase of the revolutions of the engine.**—Unlike the three previous causes this is principally dependent on the watchfulness and care of the engine room staff. The output of the boilers can be limited by partially closing the stop valves on the boilers and also on the bulkheads in connection with the main steam pipe. Engine makers generally allow a large margin for emergencies and consequently the steam valve is larger, with a correspondingly excessive lift, than is ultimately found necessary. By opening these valves to a known limited extent, priming can be greatly reduced. Reducing valves act in a similar way and have also the advantage of being automatic. A calculation of the amount of lift may be based on the following data:—

Coal burnt per I.H.P. per *hour* = K
= 2lbs. for Naval, (about).
or 1½lbs. for Mercantile marine.

water evaporated per 1lb. of coal
= 8lbs.

Volume of 1lb. of steam at working pressure
$= v$ *(See table on page 4).*

Let c = circumference of valve orifice, in inches,
x = lift of valve, in inches.

Then $c \times x$ = area through valve orifice.

The velocity of steam through valve is about 8000 feet per *minute*.

Then *volume* of steam which passes through valve per

$$minute = \frac{8000 \times c \times x}{144},$$

and the $weight = \frac{8000 \times c \times x}{144 \times v}$, and this must be equal to the weight of water evaporated in the same time

$$= \frac{8 \times K \times I.H.P.}{60}$$

$$\text{Therefore, } x = \frac{8 \times K \times I.H.P.}{60} \times \frac{144 \times v}{8000 \times c}$$

$$= \frac{3 \times K \times v}{1250 \times c} \times I.H.P. \text{ in inches.}$$

5. Irregular working.—If an automatic feed arrangement is fitted it may probably stop excessive priming from this cause and it is a pleasing feature of the present time to notice the general adoption of automatic feeding arrangements. With the large flame tube boilers it is not necessary, the percentage of feed water entering the boiler being very small compared with the water contained in the boiler, consequently it does not materially affect the water level and steam pressure. Bad stoking comes under the heading of irregular working and it is an important factor when there is any original tendency to prime from other causes, especially dirty or impure water.

6. The condition of the heating surfaces.—To obtain the best evaporative results, it is necessary to keep the heating surfaces as clean as possible. In boilers with bad circulation extreme cleanliness may cause primary locally and in the past it was not unusual to find that although priming took place when the boilers were new (i.e. perfectly clean) they did not prime subsequently (i.e. after a slight scale had been formed).

From this experience it might be inferred that a slight scale would check excessive priming and this is so in flame tube boilers, but it is impossible to obtain an equally great evaporation as with clean surfaces from the same boiler, and if we are to obtain the best results, good circulation must be combined with clean surfaces. The sea-going engineer cannot err in keeping his boilers as clean as possible. Certainly without clean heating surfaces he cannot expect to realise the highest economy. It is possible that a near approach to good results may be obtained with a slight scale on the furnaces or other heating surfaces but at any time this scale may cause a *come-down* or blister on the furnace crown or combustion chamber; priming is preferable to this. With water-tube boilers dirty heating surfaces on the water side will cause priming at a very low evaporative power, this is due to the scale becoming *detached*, not to scale adhering to the heating surface. In either case it is a loss of evaporative power.

7. **Salt or Impure Water.**—This is the greatest cause of priming in all boilers and although for other reasons it may be needful to admit salt water in small quantities to the boiler, it should be very carefully watched when high evaporative results are expected. The presence of clean salt water is not shewn until a period of working is reached, which varies with each type of boiler; this variation is nearly in proportion to the steam space provided combined with the surface area of the water at working height. Priming would be also likely to occur when the evaporation per square foot of heating surface reaches 3½ lbs. per hour. By very gradual increase of the speed, taking care that the steam pressure is not decreased at the same time, the priming may *perhaps*, and there is some slight experience to prove this, be kept within limits of safety and the evaporation increased to 7 or 8lbs., or slightly under that obtained with pure distilled water. Priming does not usually occur when the steam pressure is rising and

with very careful management in increasing the speed, it may be reduced to a certain point which is very accurately defined in "Express boilers," the various types differ much less than might be expected from their various designs. It has been stated that "express boilers" can be worked with salt water, this is perfectly true, but it is also distinctly true that there is a limit and this is not a very high one. I have seen it stated, "that certain experiments showed about three fourths of the speed of a 27 knot destroyer can be obtained with salt water." *This represents a loss of nearly seven knots and more than half the power,* and it is probably a high estimate. There is no necessity to use salt water on actual service to such an extent that the tubes become wholly choked with scale, if this happens every tube so choked will burst, of this there is no doubt whatever. In the "Naval Annual, 1897" we find it stated that a first class torpedo boat was steamed from the Thames to South America, salt water was used for the last fortnight of the voyage, and the boilers were not injured in anyway, an official trial being made after the arrival of the boat." The speed at which this voyage was made was certainly a very low one, probably ten or twelve knots, and had it been necessary, at any time after salt water had been admitted, to increase the speed to, say, twenty knots it could not have been done, although perhaps 24 knots was obtainable with clean fresh water. I must state that these remarks apply to all types of "express boilers." If "Express" boilers can always be steamed with perfectly clean fresh water, a maximum of power may be obtained at any time, but if at any moment salt or dirty water gets into the boiler, the speed and power are considerably diminished and probably the greatest power is one-half that obtainable with fresh clean water. Such conditions are not good enough for war service. Too much is expected from express boilers and there appears to be a tendency to rush into extremes; because it has been

found that the Engineers have been able to cope with this difficulty of maintaining their boilers in a high state of efficiency by enormous personal effort during peace time; it does not follow in war time, when the opportunities for cleaning and refilling boilers will be very infrequent that this state of efficiency can be maintained and it is probable that a possible 27 knots must be reduced to less than 20 because a *few gallons* of *salt water* or some other priming mixture has been admitted into the boilers. If "express" boilers are to be generally adopted for cruisers, more space and weight must be allowed than has been the case recently. Clean fresh water cannot always be maintained, on long cruises and under the varying conditions of warfare this must be exceptional. The present safe limit appears to be "natural draught" (half an inch air pressure), this will work out at about 50 horse-power per ton weight of boiler. Under these conditions the contract power will be always reliable and perhaps a greater one may be reached for short periods in emergencies. Another reason for the adoption of limit is that *the greater the forcing of the fires, the shorter the period at which the power can be maintained.*" If the speed and power are to be maintained for longer than eight hours the rate of combustion per hour should not exceed 30lbs. of coal per square foot of grate surface. Within this limit there is still a gain of about 50% on the older types of boiler.

Not the least of an engineer's troubles is the difficulty of finding a really automatically working evaporator which will not prime, when left to its "automatic" self for a few minutes. A perfectly reliable non-priming evaporator may exist but it has not been my fortune to find it when used in conjunction with water-tube boilers. A slight inattention on the part of the watch keeper and priming begins, impregnating the feed water with salt water and generally such a mixture causes intermittent and excessive priming.

When the water in the boilers becomes slightly acid, it is usual to correct this acidity, and consequent liability to corrosion, by injecting a small quantity of soda or other alkali. With the old type of boilers a large quantity of soda was used from time to time, in proper proportion to the feed admitted, this amount as a rule had no priming effect. In "express boilers" however it is a dangerous priming mixture and the Engineer has to decide on the less of two evils, priming and consequent reduction of power, or corrosion; generally priming is selected and some soda is injected with the feed water, a proportion of rather under half a pound of soda to each ton of water contained in the boiler being used. After a day or two's steaming the boilers have to be emptied and refilled and perhaps for a few days no sign of acidity is shewn, but eventually the soda process has to be repeated With "express" boilers no "sediment chamber and fittings" have as a rule been fitted and consequently it is necessary to empty the boiler into the bilge to the detriment of the framing and plates of the hull of the ship, this entails re-painting these parts throughout frequently. By adopting the "sediment chamber" system much of the priming matter could be blown out while under steam, thus assisting in the maintenance of the efficiency obtained on the original trials run under the best conditions of clean fresh water in clean boilers.

A great advance has been made by the adoption of water-tube boilers, but other conditions must be made to prevent any retrograde step by rushing into extremes. "Priming" and "forcing" so far go hand-in-hand, except that under certain very favorable conditions "forcing" can be used without "priming" occurring. Under a "forced draught" of three or four inches of air pressure the extreme power may be obtained for perhaps four hours, *if priming does not occur.* About 90 to 100 I.H.P. per ton weight of boiler is a possibility with $3\frac{1}{2}''$ to $4''$ of air pressure. Perhaps in a destroyer this

may be admissable, such extreme speeds as 30 knots may not be required for more than four hours, but when a similar air pressure is used to obtain the bare 20 knots of a cruiser, four hours is far too short. To counteract this tendency, a limit should be placed, not on the air pressure but, on the I.H.P. to be obtained per square foot of grate surface. With half an inch of air pressure it is possible to burn 30lbs. of coal per square foot of grate and this with any "express" boiler will produce about fifteen indicated horse power. In a destroyer it is necessary to burn 70lbs, or over per square foot of grate when steaming the contract speed.

Priming plays an important part in the lack of economy obtained with some boilers and probably accounts for part of the comparatively high rate of coal consumption when Belleville boilers are used. The method adopted of fitting a reducing valve at each engine only, cannot be so efficient in reducing priming as when a reducing valve is fitted on each boiler. In ordinary practice when priming occurs the speed of the engines is reduced until a safe working limit is reached; but if the speed must be maintained, the practical man *partially* closes the *boiler* stop valves, thus regulating the output of *each* boiler and within certain limits previously noticed this checks some of the priming. When priming commences in one boiler, more work is thrown on the remainder and consequently it may induce priming in some of them. The "Powerful" and "Terrible" with 48 boilers would require 48 reducing valves instead of the two now fitted, this appears rather a multiplication of fittings but a combined stop valve and reducing valve is not a difficult thing to design and the space now occupied by the great reducing valves in the engine rooms is much needed while the smaller fittings in the stokeholds would not be noticed. The slight increase in weight and expense entailed in fitting the 48 reducing valves would probably be compensated by the coal bill for 24 hours

steaming. The derangement of one or more of the 48 valves, would not appreciably affect the general working efficiency while the derangement of one of the two great valves may, and probably would, put one engine out of action, perhaps at a critical moment.

One problem still to be solved in connection with priming is, that under certain conditions one boiler may increase its output almost indefinitely even when independent reducing valves are fitted; reducing the pressure is insufficient, unless the output is also limited.

THE WATER-TUBE BOILERS OF THE INTERIM REPORT.

The present time has not been considered a convenient one for an entire revision of "A Text Book of Marine Engineering," as the change involved by the transition from the Belleville to the other types of water-tube boilers, may involve other contingent changes. In order however to keep the book up with the times and give its readers further information, it has been decided to issue a supplement which includes a description of the various types of boilers recommended for trial by the Committee. These are the Babcock and Willcox, Niclausse, Dürr and Yarrow large tube, and the Thornycroft-Marshall has also been added.

The Belleville boiler is cursed with the 'Curse of Reuben;' this is the summary of the interim report of the boiler Committee. From its design it fails to realize expectations although, with some possible improvements already indicated under the head of *Priming*, it may still hold a place in the affection of some who are most intimate with its intricacies, it does not now appeal so strongly to engineers as other and simpler boilers do. The Belleville fails in several details of actual working, either from design or difficulty in efficient manufacture. These details are summed up under their several headings as embodied by the Committee.

(*a*).—Circulation of water is defective and uncertain, because of the resistance offered by the great length of tube between the feed and steam collectors, the friction of the junction boxes, and the small holes in the nipples connecting the feed collector and generator tubes (see page 262), which also are liable to be obstructed, and may thus become a source of danger.

(*b*).—Necessity of an automatic feeding apparatus of a delicate and complicated kind.

(*c*).—Great excess of pressure required in the feeding pipes and pumps over the boiler pressure.

(*d*).—Considerable necessary excess of boiler pressure over the working pressure at the engines.

(*e*).—Water gauges not indicating with certainty the amount of water in the boiler. This has led to serious accidents.

(*f*).—Quantity of water which the boiler contains at different rates of combustion varying, although the same level may be shown on the water-gauges.

(*g*).—Necessity of providing separators with automatic blow-out valves on the main steam pipes to provide for water thrown out of the boilers when speed is suddenly increased.

(*h*).—Constant trouble and loss of water resulting from nickel sleeve-joints connecting the elements to the feed collectors.

(*i*).—Liability of the upper generator to fail by pitting or corrosion, and in economiser type, the still greater liability of the economiser tubes to fail from the same cause.

(*k*).—Cost of up-keep.

(*l*).—Necessary additional evaporating plant to make good loss of water, and their greater coal consumption on ordinary service.

Further they recommend that the separator chambers should be made larger.

The Belleville boiler has not kept abreast of the times and its short comings now place it as a competitor where once it held a supreme sway. Attention has been frequently called to its defects, and a letter in the "Engineer" of September, 1900, recapitulated these defects in detail, and it will be noticed they are practically embodied in the above report.

There is a strong natural and right-feeling disposition common to all naval officers, to make light of all their troubles and when taking evidence or listening to the words of wisdom they let fall, this personal disposition must be discounted. The Navy is alive to all the merits and defects and has thoroughly gauged the limitations of the Belleville. The Navy must be progressive, the Belleville stood for progress at the time of its adoption, it does so no longer.

As an example of its instability, the "Aboukir" consumed 20 °/₀ more coal than the "Sutlej" under apparently similar conditions. This example can be multiplied, and the uncertainty of results is lamentable. These consumption trials are an honest endeavour to obtain the truth, and although too great stress should not be placed on their exactitude, they are a distinct indication of the ways in which coal may be wasted. For some time, this difference was put down to indifferent stoking, this may be of importance but the great evil is priming, which in addition to loss of economy causes the joints of boilers and steam pipes to leak, and in some instances has involved a complete breakdown of the engines.

Priming is consistent with all the defects mentioned by the Committee, and when 450 horse power are indicated per hour from each ton of water present in the boilers at working height, priming must be lurking very near.

Only one-twentieth of the boiler steam space is allowed in the Belleville compared with the Scotch boiler. This, in itself, is sufficient to condemn the boiler, when experience has shown its failure to generate good quality steam.

Such small saving in weight effected by the adoption of the Belleville is made at the expense of the most necessary of all essentials in a good steam generator; this is the amount of water carried in the boiler at working height, and explains in great part defects (*a*), (*b*), (*c*), (*d*), (*e*), and (*f*), and probably accounts in some measure for all other defects. For a boiler in which the rate of combustion does not exceed 30 pounds of coal per square foot of grate surface, the horse power of 450 indicated per ton of water contained in the boiler when working, is enormous. Such a high figure is not admissable with economy and with the exception of some "Express" boilers which develope nearly 1000 per ton, is far larger than any type of boiler, these others generally give from 70 (in the Scotch type) to 120 I.H.P. per ton. So far as experience now shows it should never exceed 150.

Corrosion of Economiser and Generator Tubes:— The adoption of the Belleville economiser has been rendered abortive by its liability to leakage and corrosion. If carefulness of manufacture cannot overcome leakage, this defect must be attributed to defects of design or to inefficient working or both combined. The economiser is a feed heater placed immediately above the boiler proper, to abstract as much heat as it may from the heated gases on their way to the funnel. The position is theoretically most advantageous, and has proved itself practically economical in some few cases. Corrosion is

due to the air, oxygen, and possibly a small modicum of acid, set free by the application of heat to water. Distilled water contains very little air in suspension, while fresh water although much freer from air than sea water, frequently contains a large amount. Consequently the economiser setting free the air, will be least affected by distilled water pumped through it as feed to the boiler, and boilers fed with water that has been boiled or heated sufficiently to set this air free, suffer very little if at all, from corrosion. Where corrosion has been found in economisers, there generally also it will be found that salt or impure water has not been sparingly used. Any tendency to acidity is generally corrected before the feed water enters the economiser, and acidity can generally be considered as taking no part in corrosion, which is due almost entirely to freed oxygen. After steam has been raised in a boiler and consequently the air evolved from the water contained in the boiler, corrosion is almost impossible if no more air (oxygen) is admitted.

Preservation of Boilers when not under Steam :— Practice is better than theory on this subject, and as an example it may be stated that some "express" boilers were preserved on the principles stated above. The small amount of reserve feed water carried, precluded their being filled to the crown when not in use. After four years intermittent use the tubes were found in good condition and almost entirely free from corrosion; tubes were removed, cut up, examined, cleaned and weighed, and the comparative loss in weight was inappreciable.

Experience during the past ten years confirms this result, and it may be fairly concluded that corrosion in economisers is not insuperable, if sufficient heat is applied and sufficient space and time given to evolve the air before the feed water is pumped into them. It may be noticed that this statement is in agreement with the minority report which says

"that with proper precaution, the excessive corrosive decay of the tubes which has occurred in some instances, can be effectively guarded against." Excessive leakage involves the use of feed water other than distilled and thus excessive corrosion is the outcome of excessive leakage. The best of everything is good enough for the Navy, the loss from leakage of 42 tons of water by the Highflyer against 5 tons in the Minerva, is not the best.

Sweeping Tubes and cleaning the Heating Surfaces:—In cylindrical or tank boilers, it was the Admiralty custom to crowd in as much tube surface as possible by utilizing tubes of 2 to 2½ inches in diameter, while the general mercantile practice is for tubes of 4 to 4½ inches diameter. The smaller tubes were also generally longer. For trials the small tubes generally gave excellent results, the tubes were always clean both externally and internally, and the forced draught brought nearly the whole length of the tube into play as effective heating surface. On service however, the tubes could not always be kept clear of soot and small particles of ash, sometimes increased it must be confessed by injudicious use of the ash pit water service, which gradually but surely rendered about 80°/₀ of the tube heating surface inoperative. In mercantile practice however the larger diameter of tube seldom if ever becomes inefficient or inoperative and sweeping tubes under ordinary conditions is not resorted to or very necessary after many days steaming, the loss of time and steam rarely if ever compensating the increased efficiency from sweeping tubes. The efficiency of the tube is also increased by retarders.

The space about tubes in water-tube boilers also in a great degree depends on the diameter of the tubes used. With small tubes this space is small also, and after a few hours steaming becomes partially choked up, rendering the heating surface, so covered, inefficient or inoperative, and for continued

efficiency an effective means of cleaning the heating surfaces becomes necessary. Unfortunately such means are generally absent in watertube boilers, and possibly this accounts for much of the increased coal consumption of modern vessels when cruising for long distances. As an example, the Chief Engineer of a destroyer was actually accused of not steaming at the same speeds or distance because the total coal consumed was considerably less than that of other destroyers employed on the same duty. It was easily shown that the speed and distance was at least as great; the difference appeared to be due principally, if not entirely, to the fact that an efficient means of sweeping tubes did not exist in the other destroyers. The only water-tube boiler in which this desirable feature exists is the Thornycroft boiler, and it may possibly account for part of the superior economy which has generally been obtained by boilers of this description on actual service in commission. Whether under steam or not, the Thornycroft express boiler can be swept by a steam jet and more efficiently by hand. This important seagoing feature is claimed for the Thornycroft-Marshall boiler.

If the tubes of boilers are arranged in rectangular lines so that the brush can be passed between them from the stoke-hold platform, there is no difficulty, but if, as in the majority of express boilers the tubes are closely zig-zagged so that three adjacent tubes form an equilateral triangle, they can only be swept efficiently after fires are out. Tubes in cylindrical boilers are generally arranged in vertical rectangular lines, with a view to better circulation of water; for cleaning, either method is useful, but cleaning the water side can only be carried out when the boiler is not under steam.

Means of sweeping tubes by steam or air jet exist in all water-tube boilers. This method borders somewhat on the heroic and after all is very inefficient. For continued economy

and efficiency of the heating surface, a simple mechanical means is necessary which can be used when fires are alight.

The book of instructions issued by Messieurs Belleville has been carefully studied and it is not necessary to comment on it where it is in accord with the usual practice. Some peculiar information is however given here, for the general reader of engineering.

Water Level should show only 1 to 2 inches in the gauge glass when lighting up and if steam is required quickly the water should be only just showing in the gauge. When steaming, if the feed is insufficient and the water level drops below the bottom test cock on the float box, and the defect cannot be localized, put out the fire and shut off the boiler. If one or more fusible plugs melt while steaming, close the ashpits and examine tubes through sight holes; if the tubes are black watch for a few minutes and if no change takes place it is safe to open the smoke box doors and hook them back; then push fires to back of grate. If, however, the tubes are red hot, keep everything closed till they are cold, shut off graduated feed cock, to prevent any possibility of explosive generation of steam; examine boiler when cold.

(If the heating is of local nature and confined to one element, the lower orifice at the nickel ferrule is probably choked; if two or more elements, one of the feed distributors in the sediment boxes is possibly defective, and if the heating is general, it is probably due to defective working of the feed arrangement). About $\frac{1}{2}$ to $\frac{2}{3}$ glass is kept when working.

Gas Mixers:—The air blowers should be started as soon as main engines are underweigh, they should be kept at work especially when combustion is slow, and the gas mixers should remain open when cleaning fires.

The air pressure should be :—

4¼ to 5¾	lbs. per sq. in.	when burning	10¼	lbs.	Coal
5¾ to 7	„	„	„	15½	„	per 1
7 to 8½	„	„	„	20½	„	sq.ft.
8½ to 10	„	„	„	25½	„	of fire
10 to 11¼	„	„	„	30¾	„	grate.

The *fires* should be from 3 to 4 inches thick for raising steam, to 4¾ inches when steaming at full power. Fires should be cleaned half a furnace each watch. When fires are banked it is recommended they should be banked at back of furnace. (I know no reason for this, it is more convenient for future use that they be banked in front, clear of the furnace door and dead plate).

Feed Engines :—These should be eased when main engines are stopped or power considerably reduced, otherwise a quantity of water will be pumped into boilers which will be primed out of them when speed is increased. If the feed engine stops working it is probably due to racing and the consequent over-travel of slide valve. Racing is caused by feed tank being empty, by feed water too hot forming steam in end spaces of pump cylinders, or by sudden increase of delivery opening caused by feed valves opening wide, as when the engines are stopped. To restart the engines close the delivery valve, move the fork working the slide valve and then gradually re-open the delivery valve. The opening of the delivery valve regulates the engine.

Packing and Joints :—For reducing valve, stuffing box of plunger is packed with rolls of antifriction paste. For spindles of automatic blow off, use antifriction paste, (fine, loose), and the same for feed regulator spindles. A ring moulded of felted india-rubber is placed between the paste and stuffing gland; these moulded rings should be renewed

and never replaced after examination, and a new washer should never be put in without removing the old one. *Joints* of cleaning doors are made with sheet asbestos rings, dry next the doors and smeared with Belleville grease on the other side.

Lime is used to neutralize magnesium and other chlorides and fatty acids. It should be preferably quick lime slaked in a special tank, generally provided. Lime should be added to feed water in such quantity that the water should turn the natural color of litmus *blue*. For every ton of sea water about 4½ lbs. of lime should be put into tank. The water is drawn off from the tank some distance from the bottom so as to leave the lime behind.

Preservation and Cleaning Boilers :—Boilers should be emptied when cold (about 12 hours after fires are out), but it is preferable to blow out the water then by using steam from another boiler. When not in use they should be pumped quite full. They should be boiled out after steaming 800 to 1000 hours; fill the boilers to top of gauge glass with *fresh* water; put in 8 lbs. of carbonate of soda per generator-element through steam collector and close up. Then, (1), raise steam to 80 lbs. and keep it for 6 hours, without blowing off; (2), for next 6 hours burn about 8 lbs. coal per sq. ft. of grate and blow off steam produced at about 80 lbs. by opening safety valves, keeping water level at top of glass by fresh water from tanks which has been similarly treated with soda; raise steam to about 140 lbs. before drawing fires so as to leave about 80 lbs. for blowing out the water; fill boilers full immediately after blowing out and empty again when quite cold. (*Note.*—This water is an excellent priming mixture, and must all be wasted). Open out and clean boiler and tubes with steel brushes and wash out; if the boiler is not now clean and metal laid bare, repeat the process. Use the blow out about every 15 minutes from drain cock on float box, opening cock full. An air jet is sometimes used for scouring out the tubes.

The instructions do not say the cost of this process, which is almost unnecessary with other boilers where there is a good and unrestricted circulation. The cost is however considerable and the process needs repeating four times a year; it is estimated at about the following for each boiler :—

Laying fires, raising steam and steaming,		8 Tons coal.
Distilling 40 Tons of water	—	8 „
Carbonate of soda, 80 lbs per boiler, 80 lbs.		
in tank each time	—	640 lbs.
Lime for preserving when steaming say		10 cwt.

For a cruiser with 30 boilers, the weights amount to
480 tons, coal per annum.
8½ tons, carbonate of soda.
15 tons, lime.

There appears to be a very fair ground for details (*k*) and (*l*) mentioned by the Committee without further research. There is a large divergence of opinion on the advisability or necessity of this treatment, the addition of solid matter in the form of lime or carbonate of soda is probably as great a factor in producing priming as any known in ordinary practice. With other boilers sufficient alkaline material only is introduced to obtain a neutral action on litmus, without any tendency to acidity, the instructions however, aim at a blue tint produced by strong alkalinity; few but those who have tried to produce such a blue colour can appreciate the enormous quantity of lime required. The addition of less than half-a-pound of soda to one ton of water has frequently, in my experience, produced a strong tendency to priming; from this the action in the Belleville requires no strong imagination to understand when large quantities are used.

Yarrow Large Tube Boiler :—To quote Mr. Yarrow's description of them, these boilers are practically the same

whether they are of the large tube or the small tube variety as far as photographs are concerned. Illustrations of the small tube variety are shown on pages 36, 267 and 268.

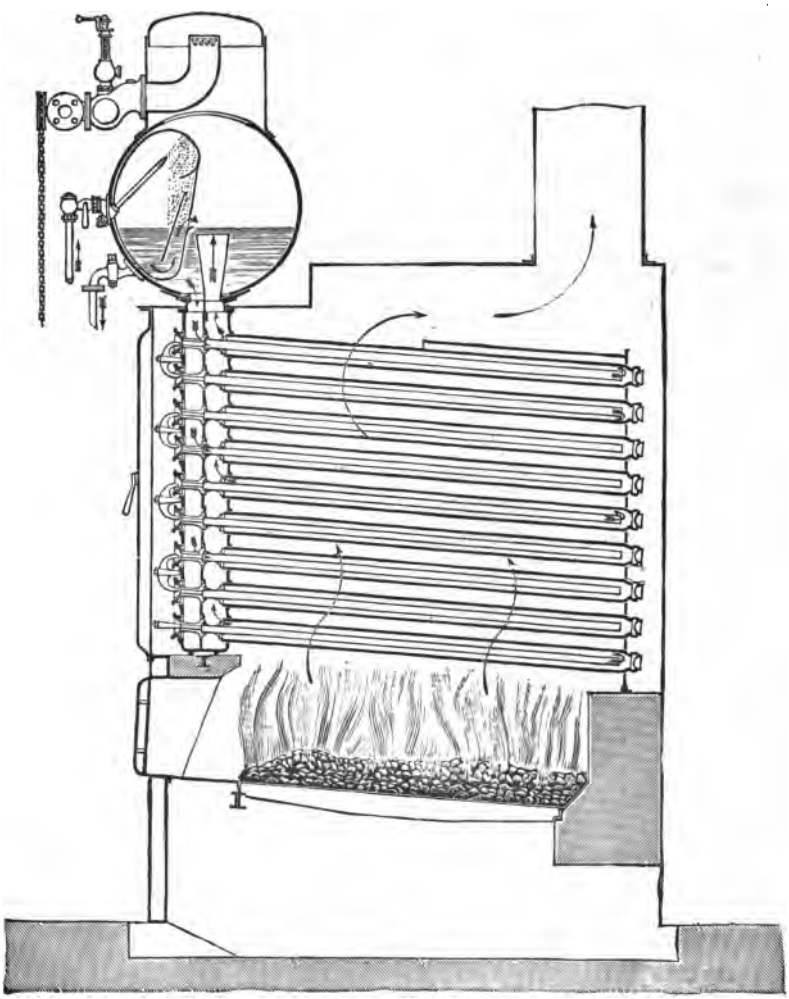
The main thing advocated by the makers for cruisers and ironclads, is to have the tube larger and thicker and a larger proportion of heating surface than for an equivalent I.H.P. in Destroyers and Torpedo boats; in fact, for a given power in a battleship or cruiser, the weight is about double what that proportion in torpedo work will give: 50°/₀ is due to the increased heating surface, and the remaining 50 °/₀ to increased durability.

The main point which is impressed upon Governments is to have uniformity of the tubes throughout the Navy, so that the tubes at least are standardized and everything connected with them interchangeable.

The size of tubes in express boilers generally lies between 1 inch and 1¼ inches diameter, the Yarrow large tube is, I believe, 1¾ inches diameter, the area of the tube is thus increased at least two and a half times. The tube heating surface of each tube, when of the same length of course, increases only 1¾ times. If only the same amount of heating surface is given per I.H.P., the weight of water contained in the tubes is increased in the greater proportion of 2½ to 1¾; this gives some indication of the influence that increased diameter of tube has on the necessarily increased weight of water carried. This increased weight of water is a most desirable feature.

Niclausse Boiler :—Six figures illustrate this boiler, fig. 1 shows a longitudinal section of the general arrangement. The course of the flames and heated gases, given off from the fuel, to the uptake is shown by the direction of the arrows. The

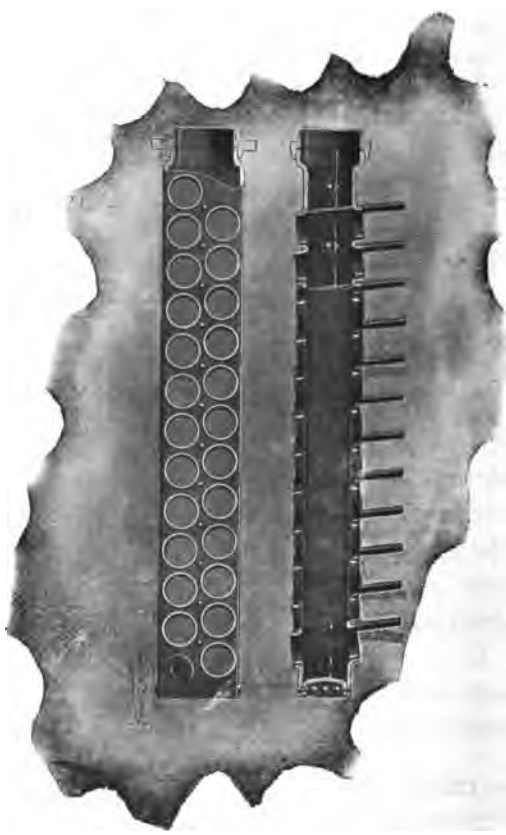
Fig. 1.—*Niclausse Boiler.*



furnace is surrounded by brickwork in the manner usual to water-tube boilers, with an outer casing of thin steel sheeting. To prevent too ready an access of the gases to the funnel, baffle plates are sometimes fitted above, and in some cases between the tubes to act as deflectors and retarders.

The **Course of Circulation** of water is also shown by arrow heads. Feed water is pumped into the steam and water receiver,(separator chamber), and descends into the front vertical collector, from whence it passes with other water already in circulation, through the interior tube which is almost, but not quite, as long as the exterior or generator tube, and then turns back along the annular space between the two tubes. The water is heated through the generator tube and finds its way into the back vertical collector, in which it

Fig. 2.—*Niclausse Vertical Collector.*



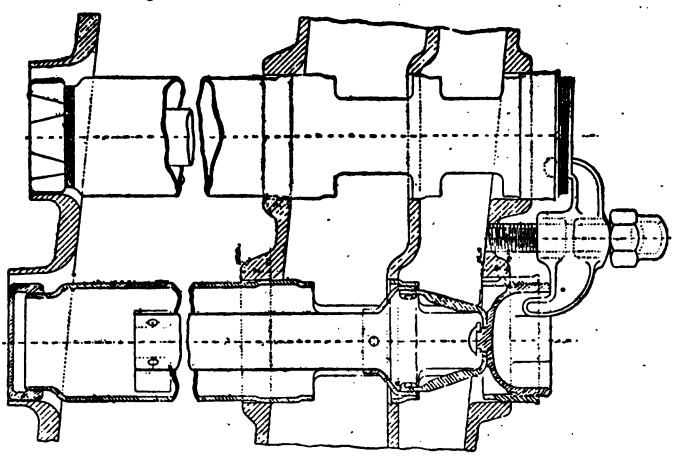
ascends with such steam as may be generated to a vertical bell mouthed fitting attached to the back collector, the top edge of this fitting is generally just below the normal working level. The generated steam escapes into the upper part of the separator chamber, while the water mixed with the feed descends through the front collector and the inner tubes back to the generating tubes. A steam dome or collector, is fitted on the separator and on it are fitted the steam valves connected to the steam pipes. Any mud or sludge evolved from the feed can be brined out by the valve shown fitted just below the water level on the separator, and in addition each vertical collector is connected at the bottom, where the sediment is most likely to settle, to a blow out pipe and cock.

The vertical collector, shown in fig. 2, is made of stamped steel and is of rectangular hollow section, (actually a rectangular tube), divided by a thin vertical plate into two parts, which are termed the front and back collectors. As the heated water and steam occupy more space than the colder descending currents, the back collector is somewhat wider than the front part. The bottom end is closed by an externally flanged plate securely rivetted and caulked. The upper end is connected to the separator chamber. The figures show a longitudinal view in part section and a front view, with tubes removed, also in part section, Each collector forms the tube plates for two vertical rows of tubes, the holes for which are echeloned, the lines joining the centres of three adjacent tubes forming nearly an equilateral triangle. For strengthening the collectors, screwed stays from front to back are also fitted as shewn, and these stays also form in addition studs by which the tube heads are secured. The unpaired hole at the bottom of each collector is connected to the blow out pipe.

The tubes are secured in pairs to the tube plates of the collector in the more recent types, by a simple arrangement

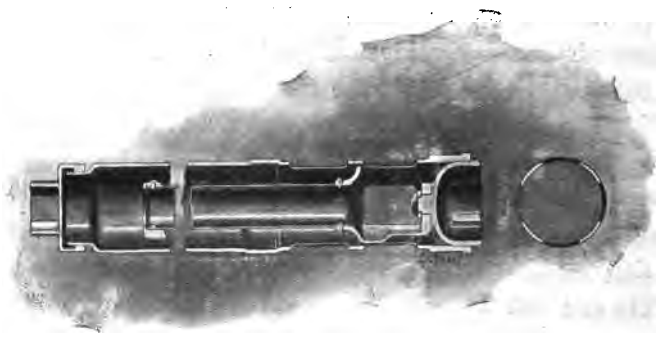
which is shown in figs. 3 and 4. Fig. 4 shows a tube element

Fig. 3.—Niclausse Tube Connection,



consisting of one generator and one circulator tube with the end closures; fig. 3 shows the connection of the tubes to the tube plates of the collector, and also at the rear end of the tube

Fig. 4.—Niclausse Tubes.



another plate which serves as a verticle support to this end. The holes in this supporting plate are sufficiently large to allow complete freedom for expansion of the tube. The generator tube is in one piece with suitable lantern orifices; its two

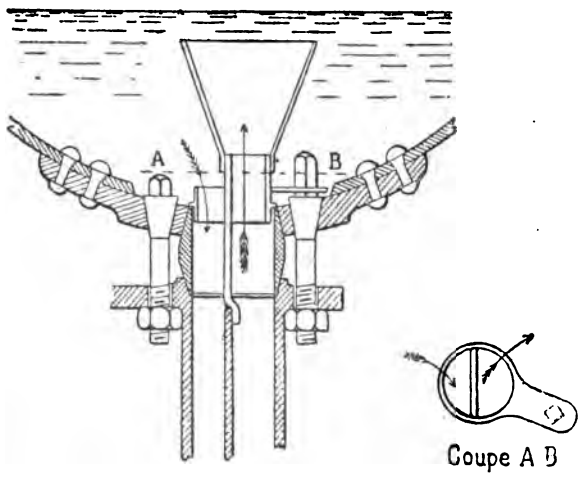
extremities are strengthened by shrinkage at the rear end, and extra thickness at the front end or tube head. The tube head has an exterior cone which fits accurately into the front tube plate, and at a suitable distance another cone fits into the back tube plate. The holes in the division plate leave the tube free. Between these two cones, openings are cut for the circulation of water and generated steam. The rear end of the tube is closed by a screwed cap slightly coned, this closure can be removed for examination of the tube, but is generally of a permanent nature. The front end or head of the generator tube is closed by a screwed cone, and to this cone is attached the interior or circulator tube. The rear end of the circulator tube is strengthened and protected by a rolled or stamped ring which may be of zinc; this ring is fitted with a lug on its lower part, and in the event of any drooping of the tube prevents it from coming in contact with the generator tube. The tubes are all inclined at an angle of about 15° to the horizontal and have a possible disadvantage in that they cannot be emptied unless they are removed from the boiler. Some objection has been taken to this non-possibity of emptying, except by a syphon, it does not however appear to be a matter of great importance and whether it is a tangible disadvantage can only be proved by experience.

The generator tubes are forced home on the conical seatings of the tube plates by a strongback, or dog, secured on the studs before mentioned, each dog secures a pair of adjacent tubes. Cleaning and examination can be performed quickly and efficiently by removing the strongback and inner tube. The tubes and seatings are standardized and it is stated that the whole of the tubes in a boiler have been renewed in four hours, Each tube has absolute freedom for longitudinal expansion, and the end pressures on the generator tube are exactly counter-balanced, consequently the strongbacks are

independent of this end pressure and serve only to keep the coned seatings properly in place and pressure tight.

An enlarged section of the lowerpart of the separator, showing its connection to the vertical collector is shown in fig. 5. The lower part of the separator is strengthened by an

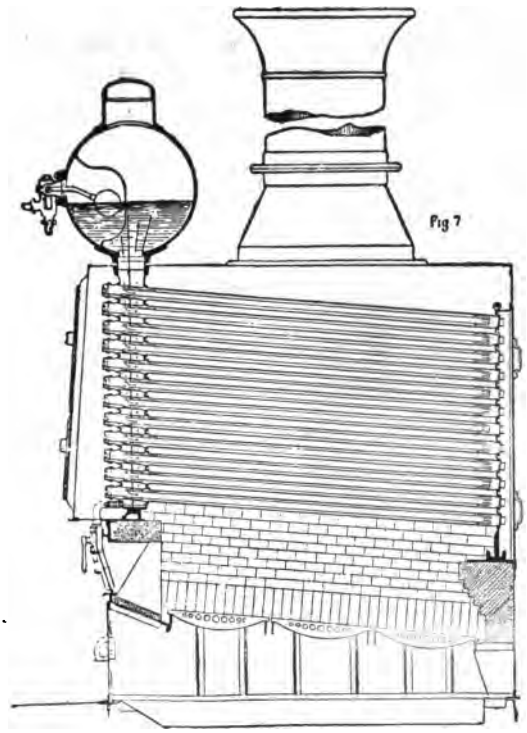
Fig. 5.—Niclausse Top Vertical Collector Junction.



extra thick plate or butt strap. This plate is bored at proper intervals for the reception of a double-coned ring, which forms the connection with the vertical collector. Pressure tightness is obtained by four coneheaded bolts and nuts, two of which are shown in the figure. The head of one of these bolts is of extra length, and over it a cap, shown in plan in **Coupe A B,** is fitted. This cap embodies the necessary lengthening of the division plate and the bell mouth for the ascending currents.

A longitudinal section of a Niclausse boiler with some of its fittings and accessories is shown in fig. 6. It also shows a system in the separator by which the working water level can be governed by means of a float operating the feed valve. The mounting of the tubes however is of older pattern than that described above.

Fig. 6.—Niclausse "Gloire" Type.



Compared with the Belleville this boiler appears to have some advantages, among them are:—

1. Greater facility for examination, cleaning and repair.
2. Less probability of water leakage.
3. Greater freedom for independent expansion of tubes.
4. Freer escape for generated steam, only one length of tube having to be traversed instead of a whole element of many tubes.
5. Greater interchangeability of tubes and other parts.
6. Possibility of more regular working.
7. No special circulation fittings.

8. Much lighter than the Belleville.

The heating surface is considerably less per I.H.P. and could probably be increased with advantage; the ratio of heating surface to grate is about the same as the Belleville. The difficulty of sweeping tubes is apparent, but as the tubes are not encumbered by any external washers or fittings, the difficulty of devising some mechanical means does not appear so great. Good trial results of fuel consumption are shown and experience only can confirm these results on active service.

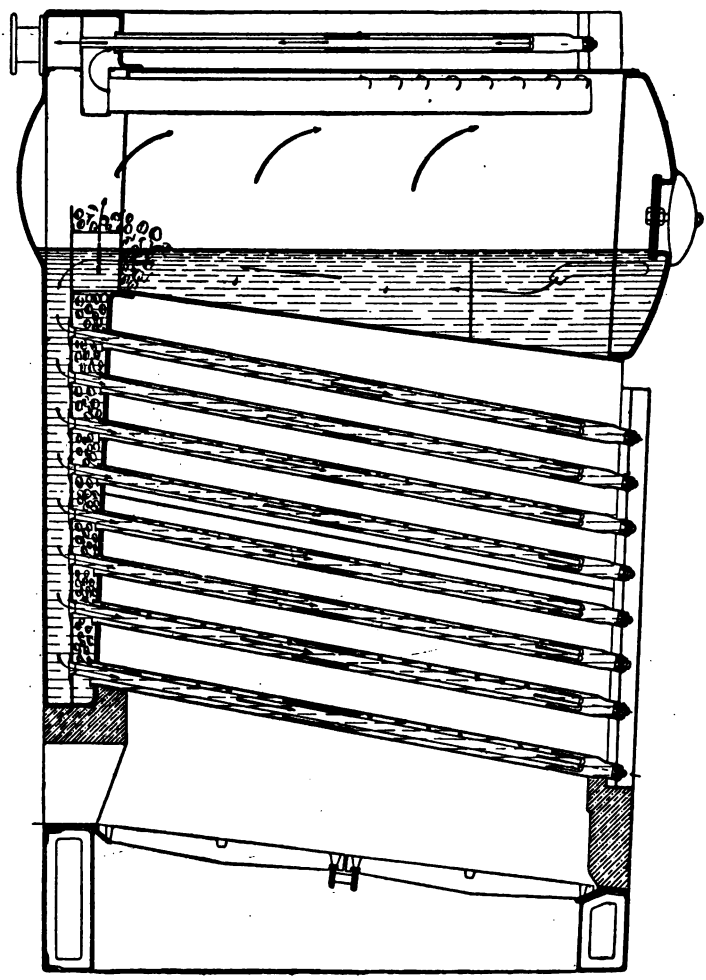
Niclausse boilers are underweigh for the "Berwick" and "Suffolk," first class armoured cruisers of 22000 I.H.P. each.

Dürr Boiler :—This boiler is very similar in general outline to the Niclausse boiler, and the course of the flames and heated gases and circulation of water are almost identical. The boilers differ however considerably in constructive details, and these are noted below. In addition a steam drier or super-heater is fitted in connection with the steam separator.

Figure 7 shows a boiler fitted with the separator, longitudinally arranged and also denotes clearly the course of circulation by arrowheads. The heated water and generated steam escape from the generator tubes into the vertical chamber, thence to the separator. The steam and such priming water as may be contained in it, passes into an internal pipe, very similar to that fitted in ordinary boilers for internal steam pipes, with slots on the upper side of the pipe; thence it passes through a series of tubes, similar to the tubes in the in the boiler but horizontally arranged, to a dome fitted on top of the separator, but not in internal connection with it except by way of the drier tubes; the stop valve connecting to the steam pipe system is fitted on this dome.

The vertical water chamber is formed in complete sheets for front and back tube plates, not in sections as in the

Fig. 7.—Durr Small Type.

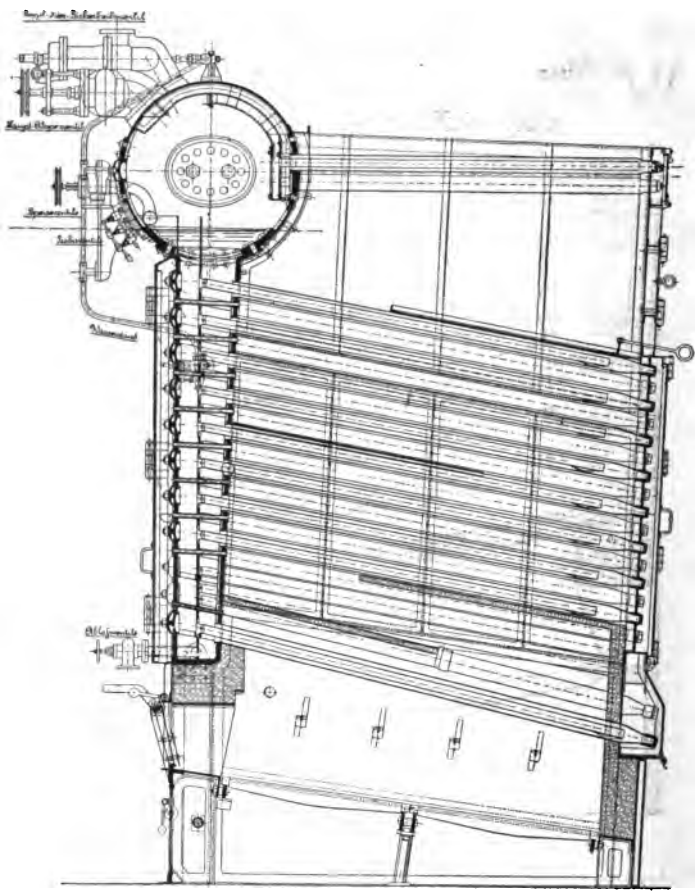


Niclausse and some other boilers. These tube plates are strongly stayed to withstand the internal pressure, and there is a division plate for circulating purposes as shown in figs. 7, 8 and 10. A drawn out flange connects the water chamber

to the cylindrical, or conical as shown in fig. 7, separator chamber.

In fig. 8, a longitudinal section is shown of a boiler with the separator arranged athwart the tube heads, similarly

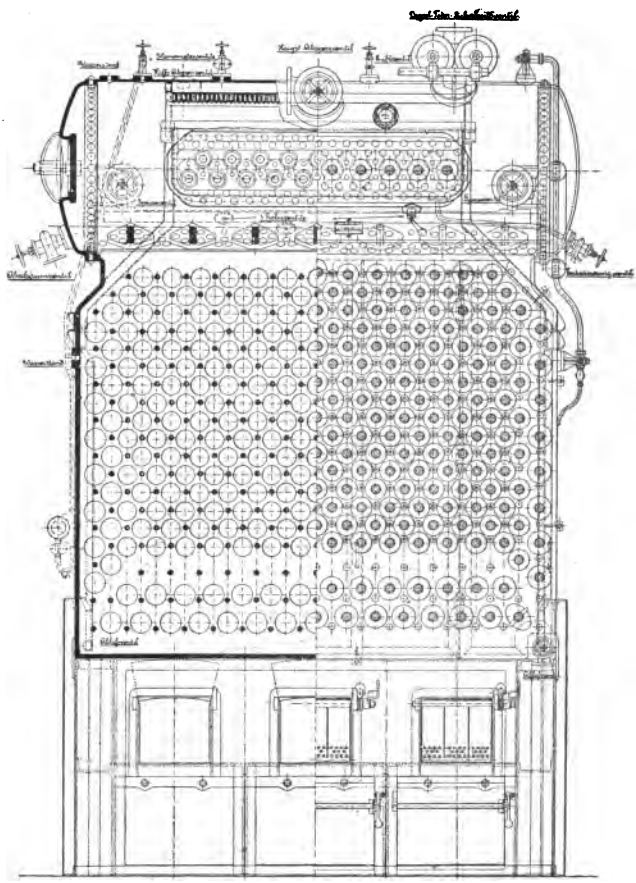
Fig. 8.—*Durr, "Prinz Heinrich."*



to the Niclausse, but connected by flanged plates, as shown. This boiler, of which a vertical section is shown in fig. 9, is

proposed for H.M.S. "Medusa," with some variation of the furnace arrangement, which is immaterial to this description.

Fig. 9.—Durr, "Prinz Heinrich."

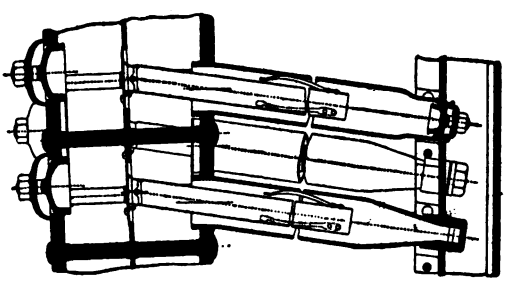


The two lower rows of tubes are at a somewhat greater inclination to the horizontal, and baffles are arranged above them for deflecting the course of the flames, and I believe are to be of cast iron for readiness of removal and renewal.

The **steam drier** is composed of two rows of tubes shorter than the boiler tubes but of similar construction. These two rows are attached to the back of the separator, and doors are arranged in front to permit of their fitting and withdrawal. Inside the separator plates are arranged so that the steam passes from the remainder of the separator to the space between them, thence through the tubes and back to the space between the inner plate and the wall of the separator; to this space the stop valve connecting to the steam pipe system is connected. The degree of drying obtained by this system is not likely, in ordinary practice, to amount to superheating and should not be inconvenient to ordinary engine practice.

The **tubes** are secured as shown in fig. 10, the outer or generator tubes are fitted with conically turned bands, (welded

Fig. 10.—*Durr Tube Connections.*



on), at their front ends, these ends are pressed, not rolled, into the conically beaded openings of the tube plate of the water chamber. As the tubes are inclined while the water chamber is nearly perpendicular, they are bent at the ends so that the axis of the tube forms an oblique angle with the ends. The inner or circulator tubes have separate flanged ends secured to the division plate, this flange supports the slight weight of the tube and keeps it in its proper central position with the assistance of coach springs shown. The rear end

of each generator tube is closed by an inner cone, turned and polished with emery and drawn tight on its seating by a cap and screwed stud. The end pressure on the tube tends to keep this cone tight and also tends to draw the tube tight into its seating on the tube plate. Opposite the head of each tube is a door and closure, this also is internally coned so that the pressure in the boiler simply presses it on its seating and to prevent any possibility of its being blown out, the closure is fitted with a small flange. The closures themselves, both front and rear, are fitted as hollow bodies, so that they are elastic and allow for a small amount of oval wear. Smoke doors are fitted at front and back of the boiler for access to the tube ends; tubes can be swept from the front or sides as convenient but there does not appear to be facility for hand sweeping when fires are alight. No packing material is used for any closure.

Brine valves are fitted to the lower part of the separator and blow out valves to the bottom of the water chamber and there are the usual fittings and boiler mountings.

The whole boiler rests in a steel frame, which is suitably covered with sheet iron, forming an airtight casing.

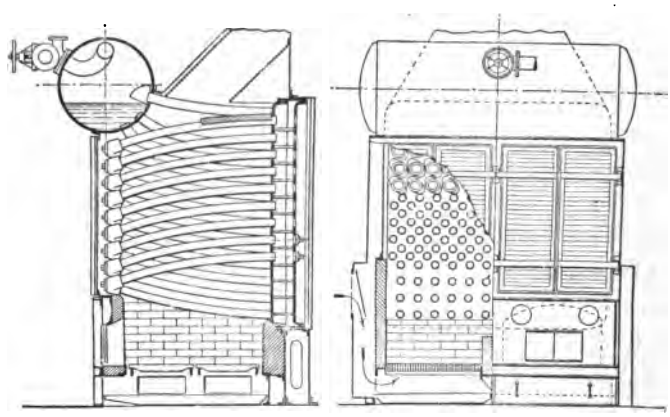
If the boilers of the "Prince Heinrich" are taken as a guide, the Dürr type is provided with 25°/₀ greater ratio of heating to grate surface, while the heating surface per horse power indicated is about the same, nearly 2¾, compared with the Belleville. Somewhat better evaporative results have been obtained and the boiler is lighter by about 30°/₀. The horse power indicated per ton of water contained in the boilers is about 156.

Thornycroft-Marshall Boiler:—This boiler must not be confounded with the Thornycroft express boiler, so extensively used in torpedo-craft and small cruisers in the British

Navy, and largely adopted in other Navies for the largest vessels also. It is a distinct type combining apparently all the best qualities of construction of other large tube boilers. It is not intended for a high degree of forcing, although there does not appear to be any defect of design to detract from a high rate of combustion. On trial the boiler has easily conformed to the Admiralty requirements when burning 18, 24 and 30 lbs. of coal per square foot of grate, and evaporating 12, 11½ and 11 lbs. per 1 lb. of coal respectively from and at 212°.

The Thornycroft-Marshall boiler is made in two types, the **sectional,** shown in fig. 12, and the **non-sectional** in fig. 11

Fig. 11.—*Thornycroft-Marshall Non-sectional.*



Referring to the latter type, it will be seen that the main features consist of a water box, generating tubes, and a horizontal separator drum, the whole being enclosed in a casing or smoke jacket, and mounted over a furnace. The front and back tube plates are well stayed together by hollow stays of nickel steel; the fracture of hollow stays makes itself known by the escape of steam or water from the hole. The tubes, which are of solid drawn steel, are all

expanded at one end into the inner plate of the water-box, which thus forms a tube plate, and opposite the mouth of each tube an aperture, covered by a door, is made in the outer or back plate of the water box for inspection and cleaning. The water box is at the back of the furnace. The generating tubes are arranged in pairs and are set with a mean inclination of 1 in $5\frac{1}{2}$ to the horizontal, and joined at the furnace door end by junction boxes. To reduce the number of doors, only one door is fitted in each junction box for gaining access to the two tubes. The tubes are slightly curved, but the radius of curvature, nearly 16 feet, is not such as to interfere with their examination; for purposes of examination these curved tubes offer some advantage over straight tubes.

The feed water is admitted into the separator drum and descends through two rows of tubes leading from below the water level in the drum to the water box. From thence the water flows into the lower generating tube of each pair, and being heated on its way, steam bubbles are formed which promote the circulation towards the junction box, owing to the upward inclination of the tube. Passing the junction box, the steam and water continue their upward flow along the upper tube of the pair, and finally escape into the water box, when the bubbles of steam ascend through the water to the top of the box and are conducted away by tubes to the separator drum near the water line. Any water carried along by the steam and discharged into the separator drum is directed downwards by the baffle hood shown, and descends again to the water box together with the new feed.

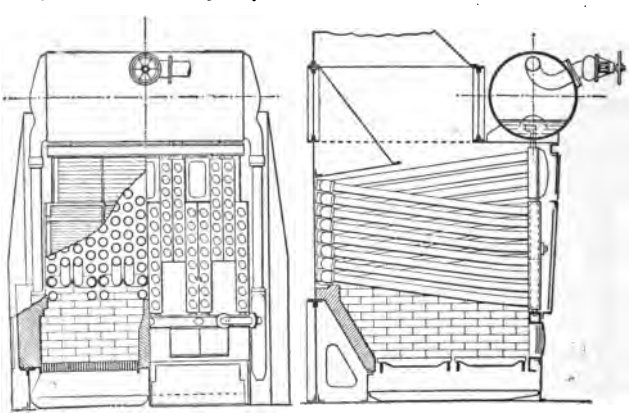
On the fire side the hot gases take a zig-zag course among the tubes to the funnel; this is affected without any baffle plates among them. The tubes in the lower part being less numerous give a chance for the furnace gases to be consumed before they have parted with so much heat as to be

brought below the temperature required for combustion. The cleaning of the tubes externally is provided for by covering doors at the sides of the casing, through which brushes may be passed among the tubes.

The head of water for circulation is not great, and the steam has also to disengage itself from the water in the water box; to counteract this, the water box is of large capacity, 8 inches wide inside, and the separator is 3 feet internal diameter. The tubes are 3¼ inches external diameter, and 7 L.S.G. or 0·176 inch thick. With such capacities as mentioned above, no reducing valve is required; only two lengths of tube are traversed with one sharp turn by the steam and water against about 20 lengths and nearly as many sharp turns in the Belleville.

The sectional type is shown in figure 12 and the water box is replaced by a series of headers, two headers with their

Fig. 12.—*Thornycroft-Marshall Sectional Boiler.*



communicating tubes forming an element. There is a feed distributing tube at the bottom connecting with the various elements, from two downcomers, one from each end of the separator drum. No valves are required to prevent reversal

of current, as in the Belleville type. There is not the same ample water space in the sectional as in the non-sectional type and although the tubes can more conveniently be straight, (this is still advocated by some engineers, but the advantage of it is extremely doubtful), the non-sectional type has the advantage of a better maintained working level due to the greater water capacity. The junction boxes in the sectional type are at the back end of the furnace. The freedom for independent expansion of the tubes is not quite so great as in the Niclausse and Dürr boilers but is superior to that of the Babcock and Willcox, and possibly of the Belleville. In the Yarrow type, with straight tubes, which is somewhat similar to the Lagrefel d' Allest, this freedom does not exist. Where the tube plate is narrow, it is perhaps of not so great a consequence and possibly this explains, together with the pliability of small thin tubes, the immunity which Yarrow express boilers have had from serious accident; to those who examined the original boilers of the "Hornet" and the various curvature of the originally straight tubes, the possibility of local strain is evident and cannot be overlooked when prospecting on a new departure. Freedom for independent expansion is an absolute necessity for safe working.

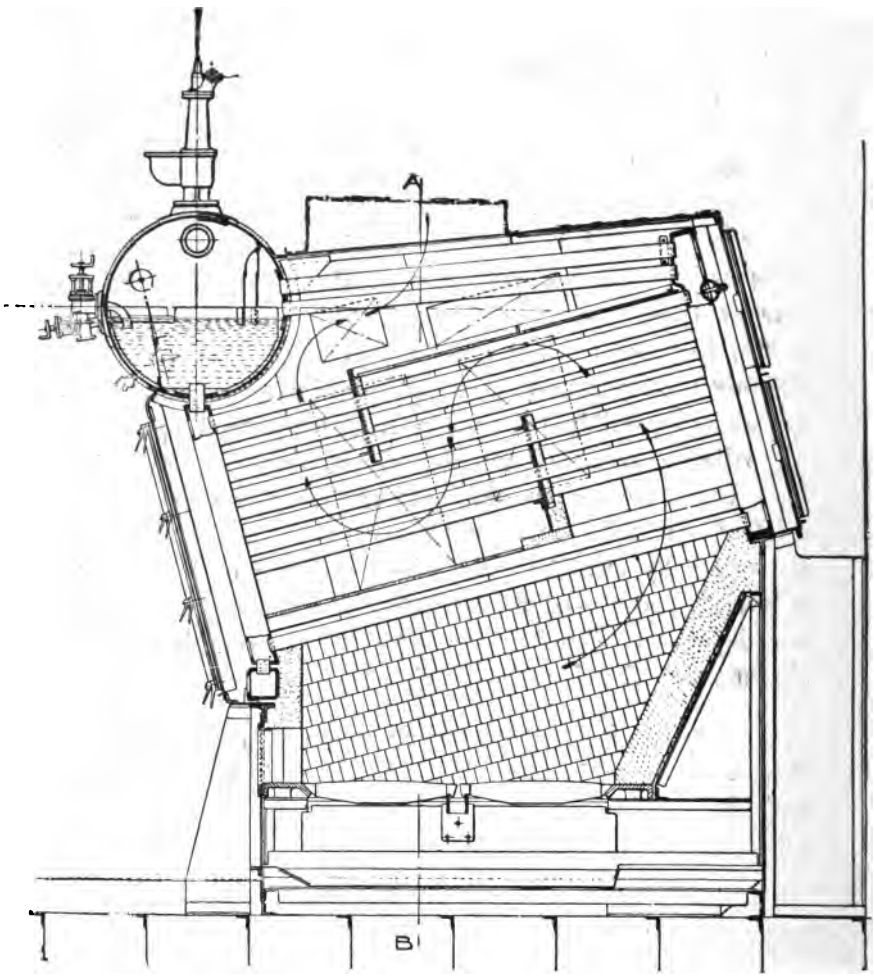
Babcock & Willcox Boiler:—In this type of boiler there are two designs, one with $1\frac{7}{8}$" tubes in the upper rows and 4 inch tubes in the two lower rows; the other has $3\frac{1}{4}$ in. tubes throughout.

The first design is more particularly used in cases where the weight and space is limited; no baffles are fitted.

In the $3\frac{1}{4}$ inch tube design, a verticle form of baffling is fitted; otherwise the designs are similar.

A longitudinal section of the latter boiler is shown in fig. 13, and the course of the flames and heated gases is indi-

Fig. 13.—*Babcock and Willcox.*



LONGITUDINAL SECTION

cated by the arrow heads. The front and back vertical water spaces are separated into sections or elements, the tube are inclined at an angle of 15° with the horizontal. Each section is made up of a series of straight tubes, **expanded** at their ends into corrugated wrought steel boxes known as "headers." The tubes are in vertical lines but echeloned to retard the escape of the products of combustion.

At the front of the boiler and above the lower end of the inclined tubes the horizontal **separator** or steam and water drum is fitted. The tops of the lower or downtake headers are connected by short vertical tubes to the lower part of the separator. The tops of the upper or uptake headers are connected by horizontal tubes to the upper part of the separator. The bottoms of the downtake headers are connected to a mud-box extending the whole width of the boiler, through which the sediment can be blown out and boiler drained. The separator is fitted with wash and dash plates to prevent undue movement of the water when the ship is rolling, with zinc plates to act against corrosion, and the usual internal steam pipe with slots.

Tube closures are not necessary but the holes opposite each end of each tube are fitted with forged steel doors drawn on to their seatings by forged steel caps and nuts; the seatings are faced and a thin gasket is used for jointing material. In the smaller tube design a coned plug with inside cone joint drawn to its seating by a faced nut making another joint on the outside, is used; the joints are faced and no jointing material is used.

Provision is made by smoke box doors, shown in figures, for access to both ends of the tubes.

The **baffles** for the 3¼ inch design are built of light fire tiles. The two lower rows of tubes are spaced some dis-

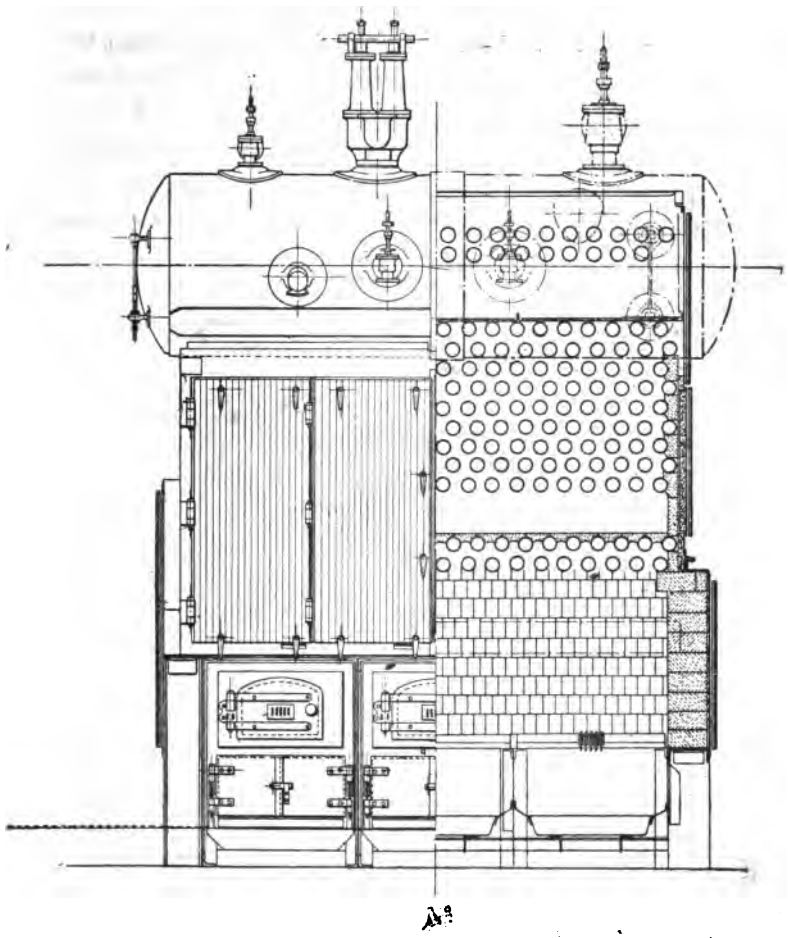
tance below the other rows and on the upper of these two a roof is supported for about two thirds of the length of the tubes from the downtake ends. At the rear end of this roof, a baffle rises almost vertically (parallel to the tube plates), and the flames are deflected over the top of this baffle and downwards by another tile roof resting on the top row of tubes; they are then deflected upwards by the lower roof and round the bottom of a second vertical baffle hanging from the front end of the top roof. The hottest part of the flames thus strike the hottest part of the tubes and after parting with some of their heat, finally leave the boiler where the tubes are least heated next the down-comers They then pass between the drier tubes.

A front view and section of the boiler is shown in figs. 13 & 14, and the arrangement of tubes is clearly indicated in them. The steam drier tubes are somewhat shorter but of similar diameter to the generator tubes, the front ends are expanded into the separator.

Experiments for testing the water circulation tend to show that the boiler will stand forcing and that the circulation aids materially in keeping the temperature of the tubes uniform and thus prevents to a large extent unequal expansion. The freedom for independent expansion of the tubes is limited, with unrestricted circulation the expansion should not under ordinary conditions be excessive; this is a question of experience.

A short time since a good feature of this boiler, which is shared by some others, was brought under my notice. Boilers were required for mining works near the top of a stiff hill, and to get them there they were more conveniently conveyed through the tunnel workings, an easy matter with this boiler but impossible with ordinary Scotch boilers. This

Fig. 14.—*Babcock and Willcox.*



facility of portability and erection is a most important feature in warships, and is a great advantage of watertube boilers; it is generally confined to the sectional types.

A saving of from 30 to 40 °/₀ of weight is claimed by the makers of this boiler over the ordinary cylindrical boiler.

The casings and general arrangement of the exterior is shown in figures 15 and 16. Hinged doors are fitted at front,

Fig. 15.—*Babcock and Willcox.*

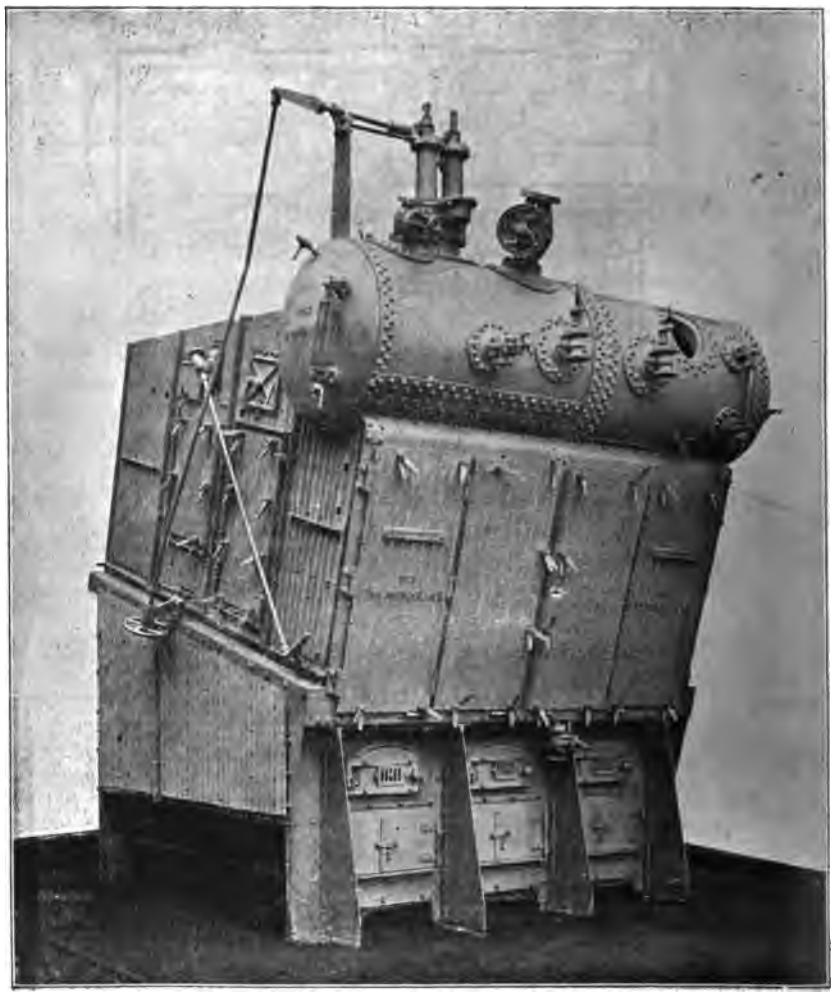
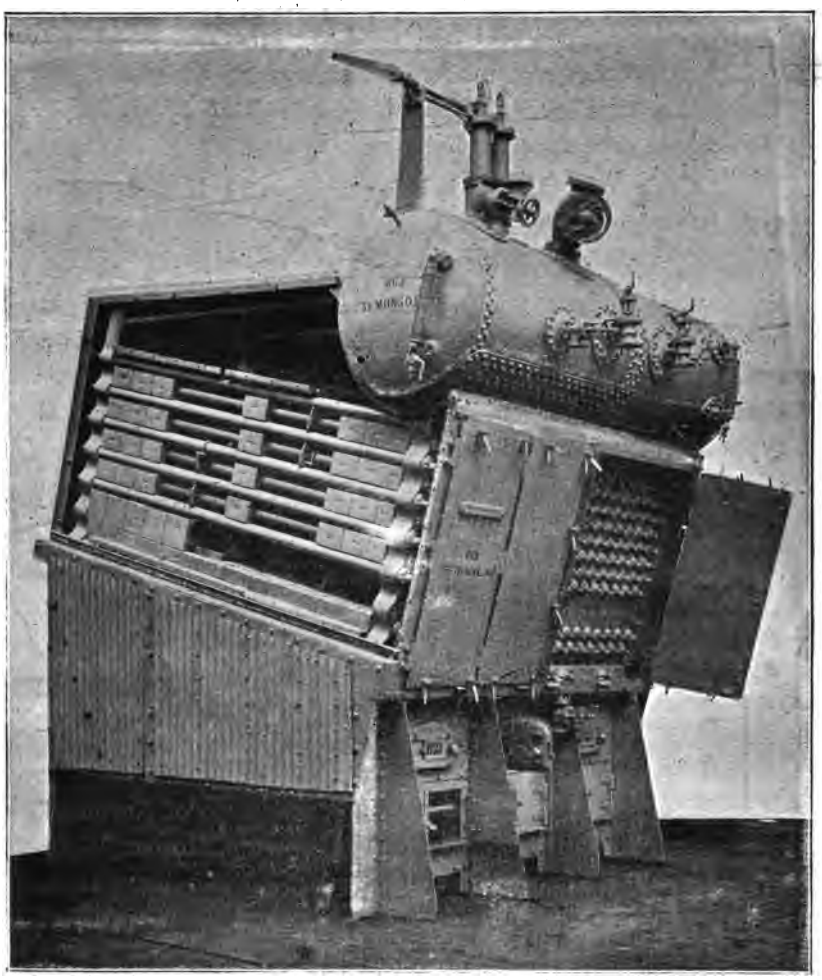


Fig. 16.—*Babcock and Willcox.*



rear and sides for access to hand hole fittings and cleaning out soot and ashes. The furnaces are of the usual brickwork kind but sometimes specially light fire tiles are bolted to the furnace sides.

Satisfactory trials are reported from the gunboat "Sheldrake," but remembering our recent experiences of the Belleville after satisfactory results had been reported from the "Sharpshooter," it is probably wiser to reserve any opinion on this, or any other type, until some larger plant has been tried. The "Challenger" of 12,500 and "Hermes" of 10,000 I.H.P. should soon give a more reliable report.

This type of boiler is being fitted in 14 United States cruisers and in one battleship.

Performances of Water Tube Boilers:—Although the figures given on pages 39 and 40 require some slight modification, the remarks are still true to-day. There is a tendency to equalise the weights or rather the horse power obtained for a given weight in each of the four principal types of water-tube boilers, these types are:—

(1).—Belleville, Niclausse & Dürr, with large tubes, 4½ to 5 in. diameter.

(2).—Belleville, (Sharpshooter), Thornycroft-Marshall (sectional and non-sectional), Babcock & Willcox, with tubes 3 to 3¼ in. diameter.

(3).—Yarrow, (large tube), Babcock & Willcox (with 2 lower rows 4 inches diameter), with tubes 1¾ to 2 inches diameter.

(4).—Boilers of "Express" type, consisting of Normand, Reed, Schultz, Du Temple, Townly, Mosher, Ward, Thornycroft ("Speedy" type,) all these have tubes with small radius curvature; the Thornycroft ("Daring" improved type), and Blechynden boilers have tubes with large radius curvature, and the Yarrow has straight tubes, some, however, have curved ends where they join the tube plates The diameter of "Express" boiler tubes is generally from 1 to 1¼ in.

Within moderate limits, the smaller the tube the greater the power for weight. All "Express" boilers are of the non-sectional type, and to these can be added the Yarrow large tube, Dûrr and Thornycroft-Marshall (non-sectional). There is some difficulty in substituting these last two types in ships already constructed, but each case must be considered on its merits, as some saving in weight is affected, and there is a larger amount of water in the boiler, and better circulation with less tendency to priming.

On a basis of burning 30 lbs. per sq. foot of grate surface for naval purposes, about 450 horse power are developed, per ton of water at working height in the Belleville, while from 70 (in the cylindrical) to 156 are developed in the others, leaving out express types which when burning 75 to 100 lbs. per square foot of grate develope about 1000. Priming and contingent evils are possible when this figure reaches 150.

The proportions and requirements for a good and economical water-tube boiler are somewhat as below. Ratio of heating surface to grate surface, 42 to 45. Heating surface per I.H.P. 3 to 3½ square feet, when developing 15 horse power per square foot of grate. The weight of steam produced per hour should not generally exceed the weight of water contained in the boiler when working.

The steam space should be not less than one quarter cubic foot per indicated horse power.

The evaporation per 1lb. of good coal should not be less than 11lbs. of water, from and at 212°.

The rate of evaporation per sq. ft. of heating surface should not exceed 5lbs. per hour.

The circulation should be natural, unrestricted and not tortuous, and some means for dividing the up-cast from the down-coming circulation is advisable.

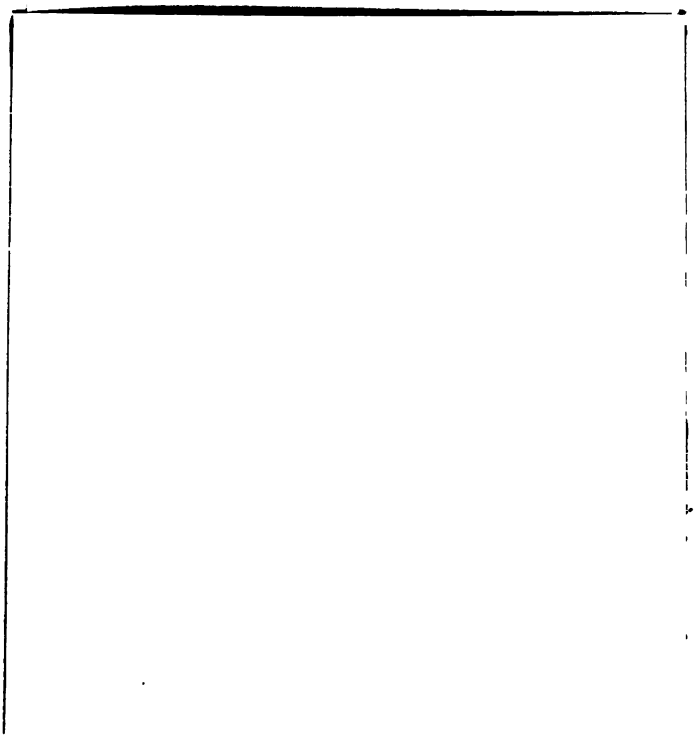
Provision should be made for effectively preventing any end pressure on the tubes forcing them out of the tube plates. The ash pit, furnace and other doors, should be self-closing. The tubes and heating surfaces should be sufficiently accessible when fires are alight to permit of hand sweeping as well as by steam jet.

Cleaning and completely emptying should be easy and expeditious.

If all these points are embodied, no special apparatus should be necessary, such as gas mixers and plant, reducing valves, automatic blow outs and specially delicate automatic feeds; and above all no priming should take place. A consumption of coal not exceeding 1½lbs. per I.H.P. per hour, may be reasonably expected and under favorable conditions better results should be attained.

8908967728O

B89089677280A







8908967728O

b89089677280a